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Kishigami et al.

(10) **Patent No.: US 9,097,791 B2**
(45) **Date of Patent: Aug. 4, 2015**

(54) **RADAR DEVICE**

(75) Inventors: **Takaaki Kishigami**, Tokyo (JP); **Hirohito Mukai**, Tokyo (JP); **Yoichi Nakagawa**, Tokyo (JP)

(73) Assignee: **Panasonic Intellectual Property Management Co., Ltd.**, Osaka (JP)

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(21) Appl. No.: **13/807,189**

(22) PCT Filed: **Jul. 1, 2011**

(86) PCT No.: **PCT/JP2011/003786**

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PCT Pub. Date: **Jan. 19, 2012**

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(30) **Foreign Application Priority Data**

Jul. 16, 2010 (JP) 2010-161799

(51) **Int. Cl.**
G01S 13/08 (2006.01)
G01S 7/35 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC . ***G01S 7/35*** (2013.01); ***G01S 7/285*** (2013.01); ***G01S 7/4021*** (2013.01); ***G01S 13/42*** (2013.01); *G01S 13/931* (2013.01)

(58) **Field of Classification Search**
CPC G01S 7/35; G01S 13/42; G01S 13/931; G01S 7/285; G01S 7/4021
USPC 342/189, 202
See application file for complete search history.

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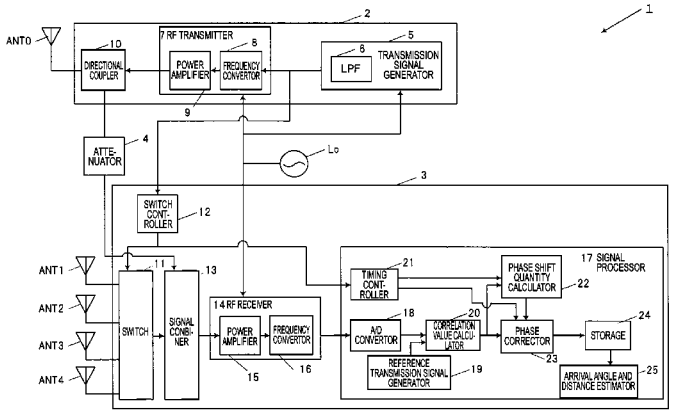
Primary Examiner — Timothy A Brainard
(74) *Attorney, Agent, or Firm* — Seed IP Law Group PLLC

(57) **ABSTRACT**

The disclosed technique includes transmitting a signal intermittently according to a transmission cycle having a predetermined transmission period and a non-transmission period; receiving the signal reflected from a target with reception antennas; and detecting the target from the reflected signal. A high-frequency transmission signal attenuated during the transmission period and a receipt signal received during the non-transmission period are combined together. A correlation value between a reference transmission signal and the receipt signal in the combined signal is calculated, and the amount of phase shift in an arbitrarily selected reception antenna is calculated from the correlation value of a reference reception antenna, and the correlation values of the other reception antennas. The phase component of the correlation value of the arbitrarily selected reception antenna is corrected on the basis of the amount of phase shift.

13 Claims, 13 Drawing Sheets



(51) **Int. Cl.**

G01S 7/285	(2006.01)
G01S 7/40	(2006.01)
G01S 13/42	(2006.01)
G01S 13/93	(2006.01)

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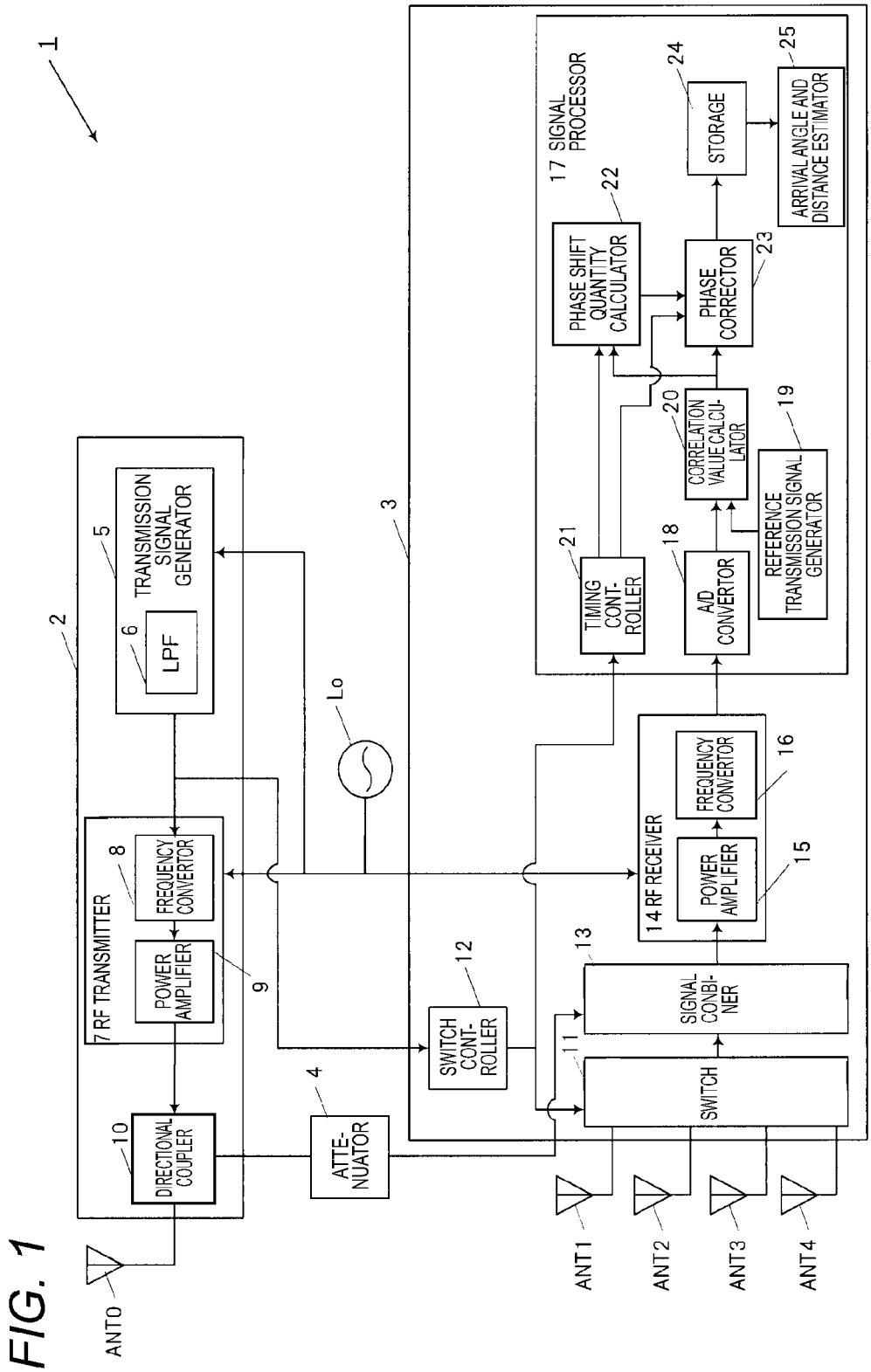

1
2
3
4
5
6
7 RF TRANSMITTER
8
9
10
11
12
13
14 RF RECEIVER
15
16
17 SIGNAL PROCESSOR
18
19
20
21
22
23
24
25
TRANSMISSION SIGNAL GENERATOR
LPF
FREQUENCY CONVERTOR
POWER AMPLIFIER
DIRECTIONAL COUPLER
ATTE-NUATOR
SWITCH CONT-ROLLER
SIGNAL CONBI-NER
SWITCH
POWER AMPLIFIER
FREQUENCY CONVERTOR
A/D CONVERTOR
REFERENCE TRANSMISSION SIGNAL GENERATOR
CORRELATION VALUE CALCU-LATOR
TIMING CONT-ROLLER
PHASE SHIFT QUANTITY CALCULATOR
PHASE CORRECTOR
STORAGE
ARRIVAL ANGLE AND DISTANCE ESTIMATOR
Lo
ANT0
ANT1
ANT2
ANT3
ANT4

FIG. 1

FIG. 2

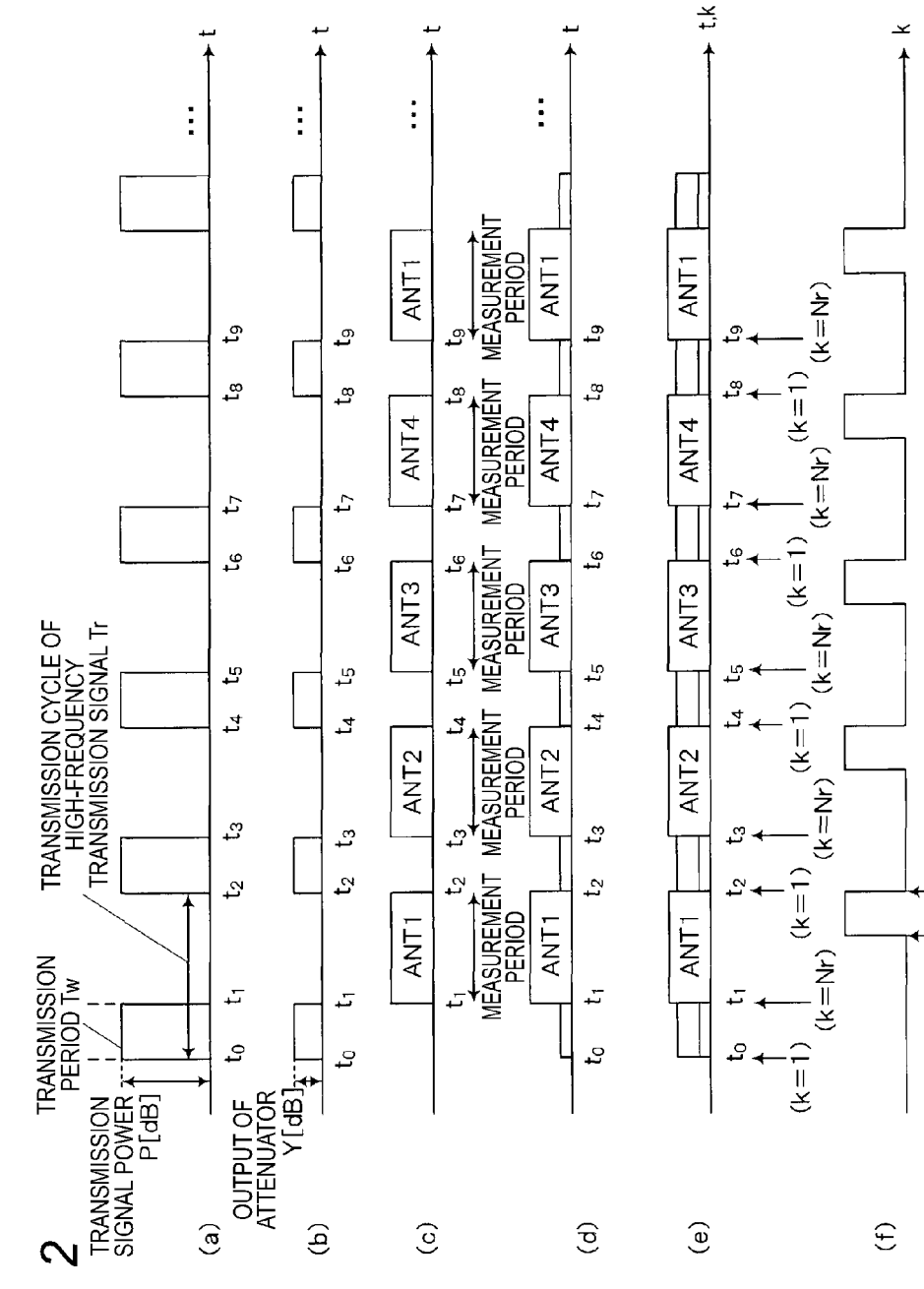
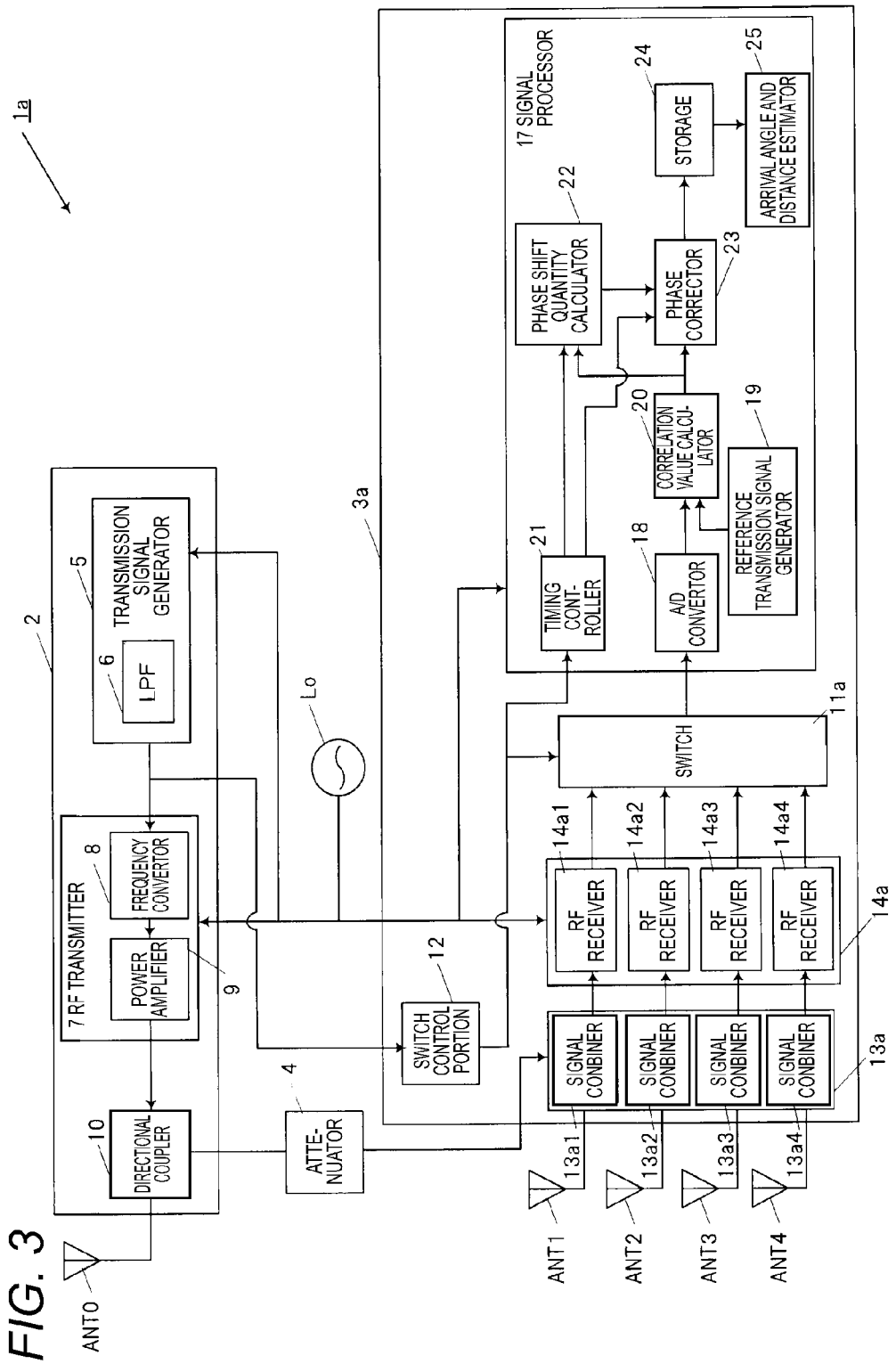
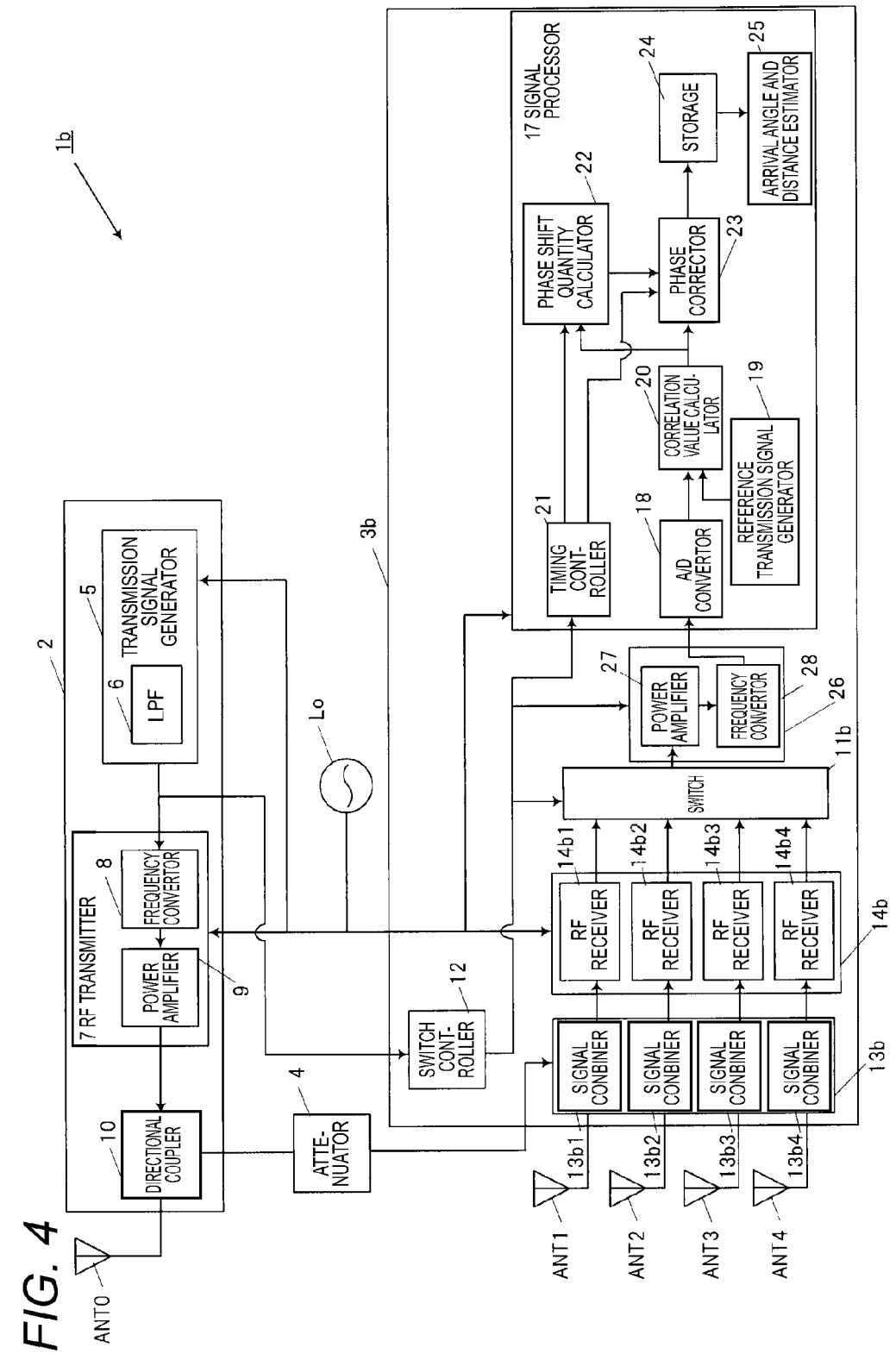

TRANSMISSION PERIOD Tw
TRANSMISSION CYCLE OF HIGH-FREQUENCY TRANSMISSION SIGNAL Tr
TRANSMISSION SIGNAL POWER P[dB]
OUTPUT OF ATTENUATOR Y[dB]
(a)
(b)
(c)
(d)
(e)
(f)
ANT1
ANT2
ANT3
ANT4
MEASUREMENT PERIOD
(k=1)
(k=Nr)
(k=2Nr)
(k=Nr+Nu)
t
t,k
k

FIG. 3


1a
2
3a
4
5
6
7 RF TRANSMITTER
8
9
10
11a
12
13a
13a1
13a2
13a3
13a4
14a
14a1
14a2
14a3
14a4
17 SIGNAL PROCESSOR
18
19
20
21
22
23
24
25
ANT0
ANT1
ANT2
ANT3
ANT4
Lo
TRANSMISSION SIGNAL GENERATOR
LPF
FREQUENCY CONVERTOR
POWER AMPLIFIER
DIRECTIONAL COUPLER
ATTE-NUATOR
SWITCH CONTROL PORTION
SIGNAL COMBINER
RF RECEIVER
SWITCH
TIMING CONT-ROLLER
A/D CONVERTOR
REFERENCE TRANSMISSION SIGNAL GENERATOR
CORRELATION VALUE CALCU-LATOR
PHASE SHIFT QUANTITY CALCULATOR
PHASE CORRECTOR
STORAGE
ARRIVAL ANGLE AND DISTANCE ESTIMATOR


1b
2
3b
4
5
6
7 RF TRANSMITTER
8
9
10
11b
12
13b
13b1
13b2
13b3
13b4
14b
14b1
14b2
14b3
14b4
17 SIGNAL PROCESSOR
18
19
20
21
22
23
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25
26
27
28
ANT0
ANT1
ANT2
ANT3
ANT4
TRANSMISSION SIGNAL GENERATOR
LPF
FREQUENCY CONVERTOR
POWER AMPLIFIER
DIRECTIONAL COUPLER
ATTE-NUATOR
Lo
SWITCH CONT-ROLLER
SIGNAL CONBINER
RF RECEIVER
SWITCH
POWER AMPLIFIER
FREQUENCY CONVERTOR
TIMING CONT-ROLLER
A/D CONVERTOR
REFERENCE TRANSMISSION SIGNAL GENERATOR
CORRELATION VALUE CALCU-LATOR
PHASE SHIFT QUANTITY CALCULATOR
PHASE CORRECTOR
STORAGE
ARRIVAL ANGLE AND DISTANCE ESTIMATOR

FIG. 4

FIG. 5

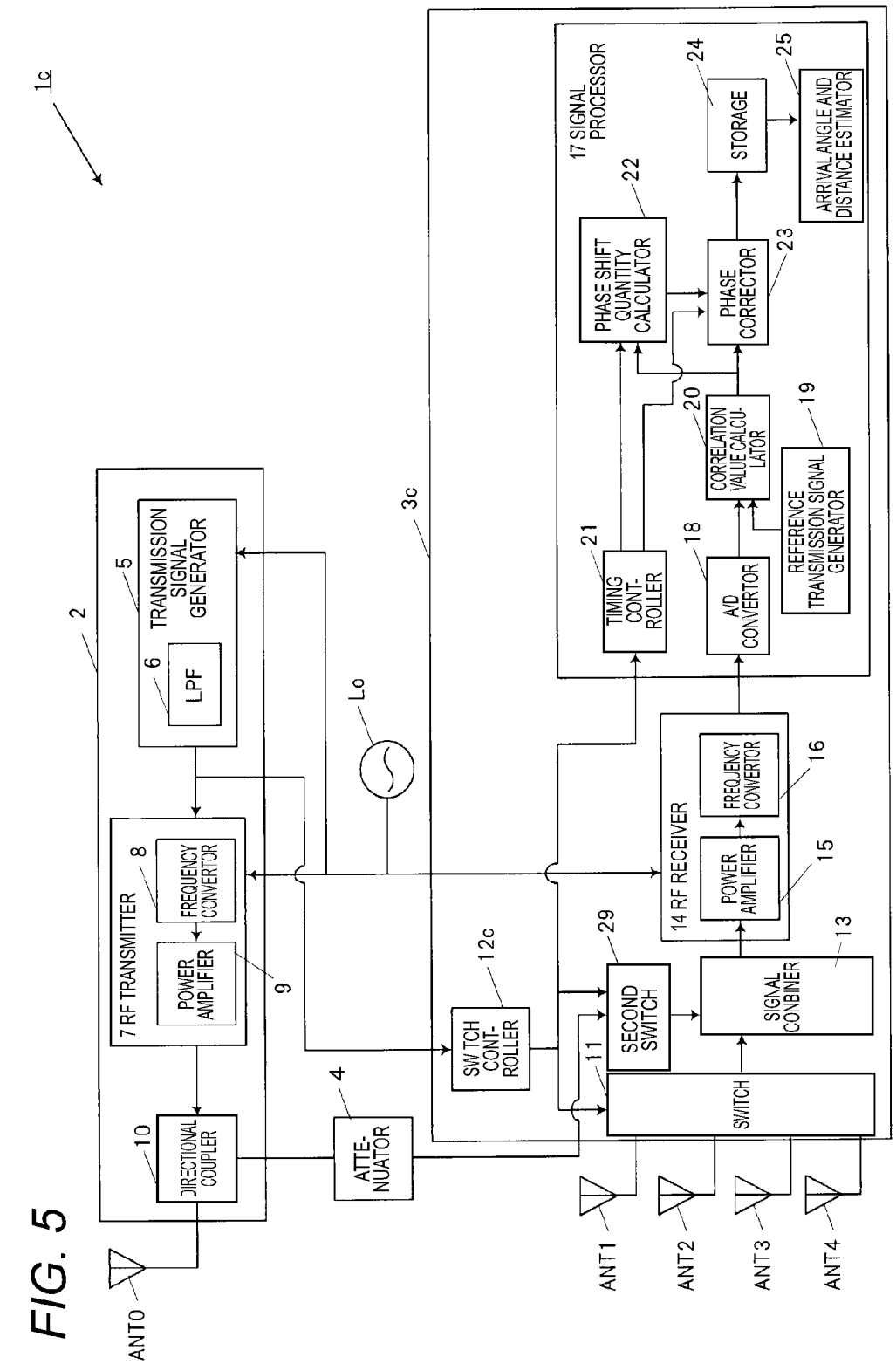
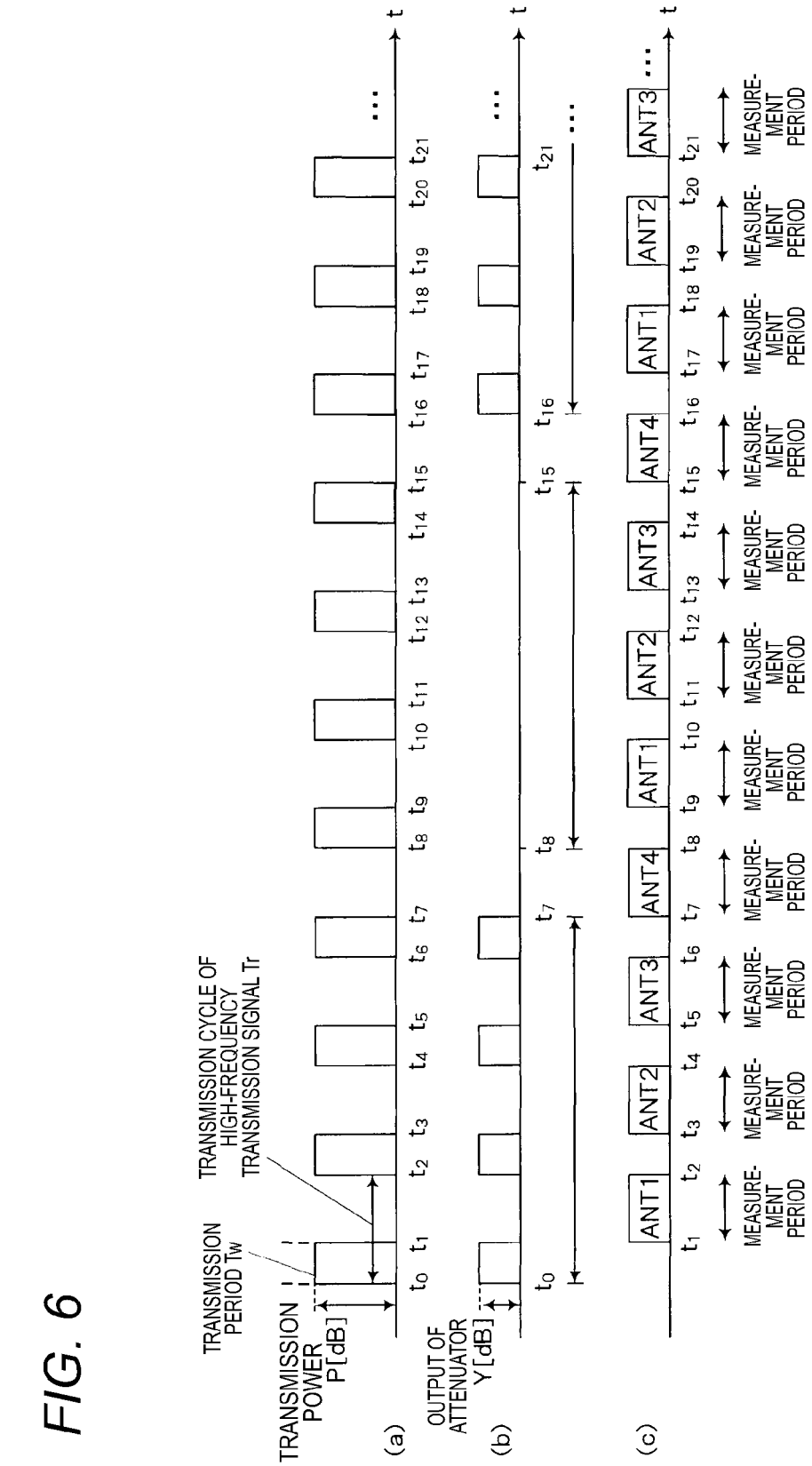

1c
2
3c
4
5
TRANSMISSION SIGNAL GENERATOR
6
LPF
7 RF TRANSMITTER
8
FREQUENCY CONVERTOR
POWER AMPLIFIER
9
10
DIRECTIONAL COUPLER
ATTE-NUATOR
Lo
12c
SWITCH CONT-ROLLER
11
SECOND SWITCH
SWITCH
13
SIGNAL COMBINER
14 RF RECEIVER
15
POWER AMPLIFIER
16
FREQUENCY CONVERTOR
17 SIGNAL PROCESSOR
18
A/D CONVERTOR
19
REFERENCE TRANSMISSION SIGNAL GENERATOR
20
CORRELATION VALUE CALCU-LATOR
21
TIMING CONT-ROLLER
22
PHASE SHIFT QUANTITY CALCULATOR
23
PHASE CORRECTOR
24
STORAGE
25
ARRIVAL ANGLE AND DISTANCE ESTIMATOR
ANT0
ANT1
ANT2
ANT3
ANT4

FIG. 6


TRANSMISSION PERIOD Tw
TRANSMISSION CYCLE OF HIGH-FREQUENCY TRANSMISSION SIGNAL Tr
TRANSMISSION POWER P[dB]
OUTPUT OF ATTENUATOR Y[dB]
(a)
(b)
(c)
t
t0 t1 t2 t3 t4 t5 t6 t7 t8 t9 t10 t11 t12 t13 t14 t15 t16 t17 t18 t19 t20 t21
ANT1
ANT2
ANT3
ANT4
MEASURE-MENT PERIOD

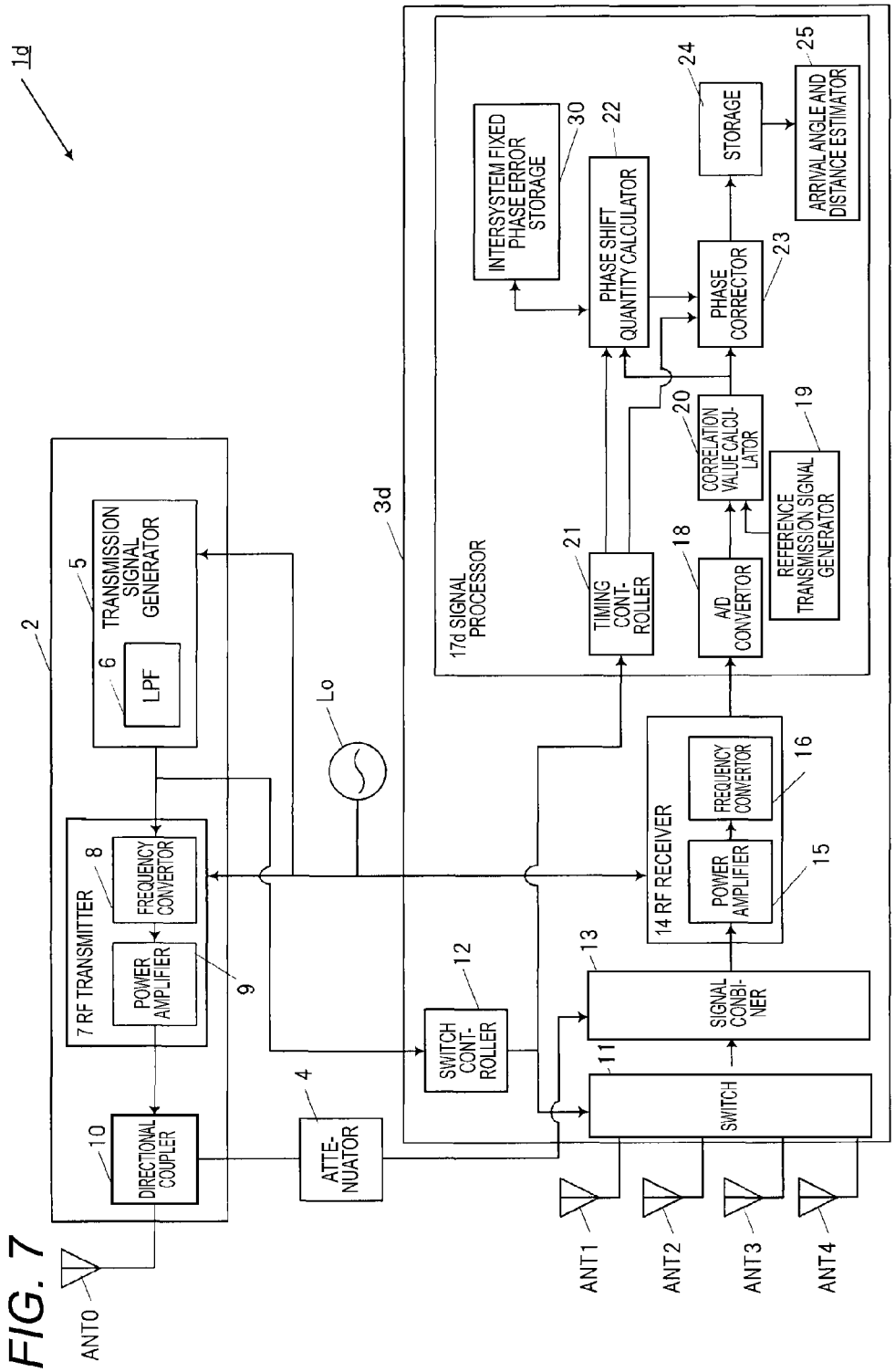

1d
2
3d
4
5
TRANSMISSION SIGNAL GENERATOR
6
LPF
7 RF TRANSMITTER
8
FREQUENCY CONVERTOR
POWER AMPLIFIER
9
10
DIRECTIONAL COUPLER
ATTE-NUATOR
Lo
11
SWITCH
12
SWITCH CONT-ROLLER
13
SIGNAL COMBI-NER
14 RF RECEIVER
15
POWER AMPLIFIER
16
FREQUENCY CONVERTOR
17d SIGNAL PROCESSOR
18
A/D CONVERTOR
19
REFERENCE TRANSMISSION SIGNAL GENERATOR
20
CORRELATION VALUE CALCU-LATOR
21
TIMING CONT-ROLLER
22
PHASE SHIFT QUANTITY CALCULATOR
23
PHASE CORRECTOR
24
STORAGE
25
ARRIVAL ANGLE AND DISTANCE ESTIMATOR
30
INTERSYSTEM FIXED PHASE ERROR STORAGE
ANT0
ANT1
ANT2
ANT3
ANT4

FIG. 7

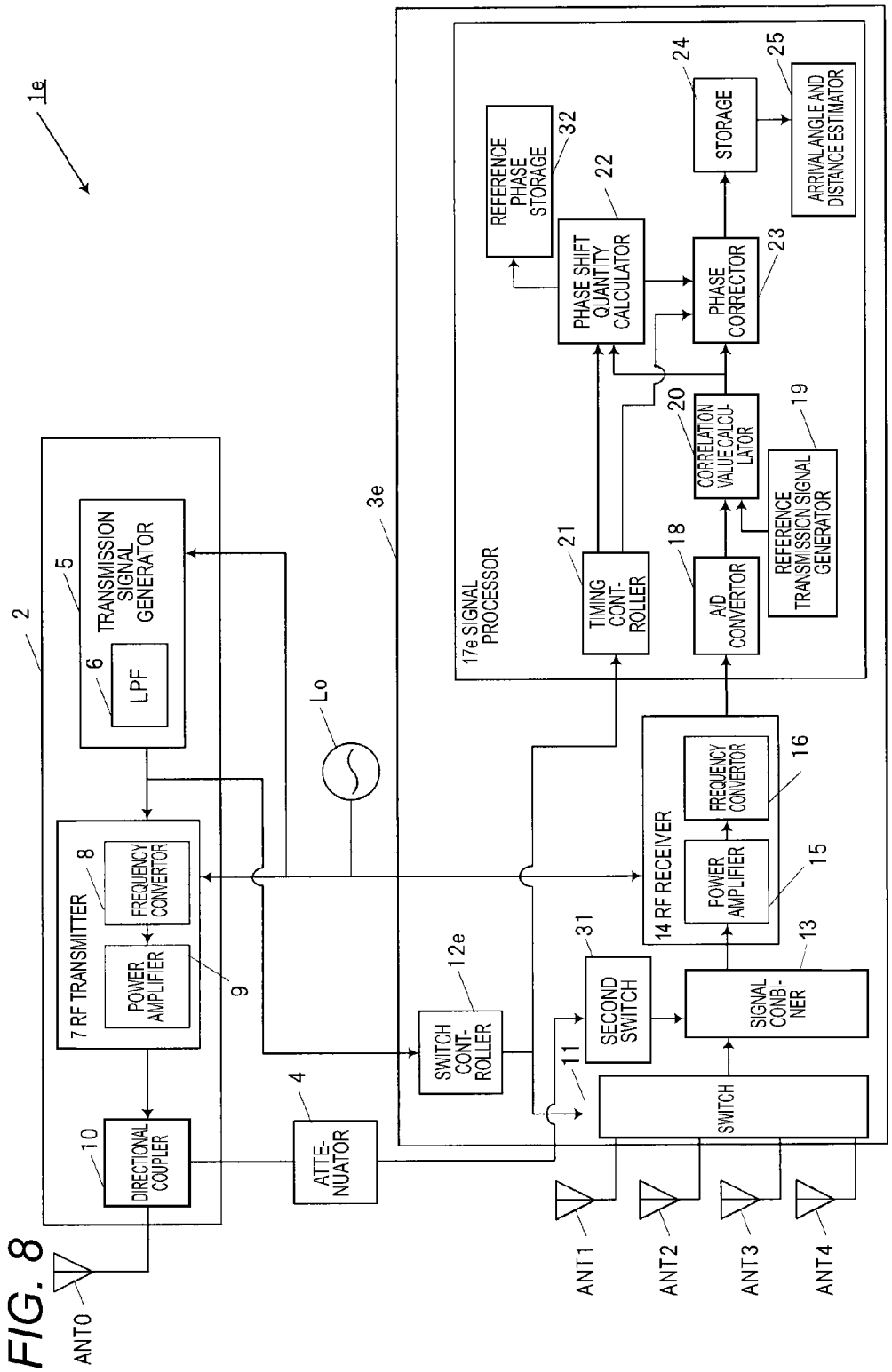

1e
2
3e
4
5
6
7 RF TRANSMITTER
8
9
10
11
12e
13
14 RF RECEIVER
15
16
17e SIGNAL PROCESSOR
18
19
20
21
22
23
24
25
31
32
ANT0
ANT1
ANT2
ANT3
ANT4
Lo
TRANSMISSION SIGNAL GENERATOR
LPF
FREQUENCY CONVERTOR
POWER AMPLIFIER
DIRECTIONAL COUPLER
ATTE-NUATOR
SWITCH CONT-ROLLER
SECOND SWITCH
SWITCH
SIGNAL COMBI-NER
POWER AMPLIFIER
FREQUENCY CONVERTOR
TIMING CONT-ROLLER
A/D CONVERTOR
CORRELATION VALUE CALCU-LATOR
REFERENCE TRANSMISSION SIGNAL GENERATOR
PHASE SHIFT QUANTITY CALCULATOR
PHASE CORRECTOR
REFERENCE PHASE STORAGE
STORAGE
ARRIVAL ANGLE AND DISTANCE ESTIMATOR

FIG. 8

FIG. 9

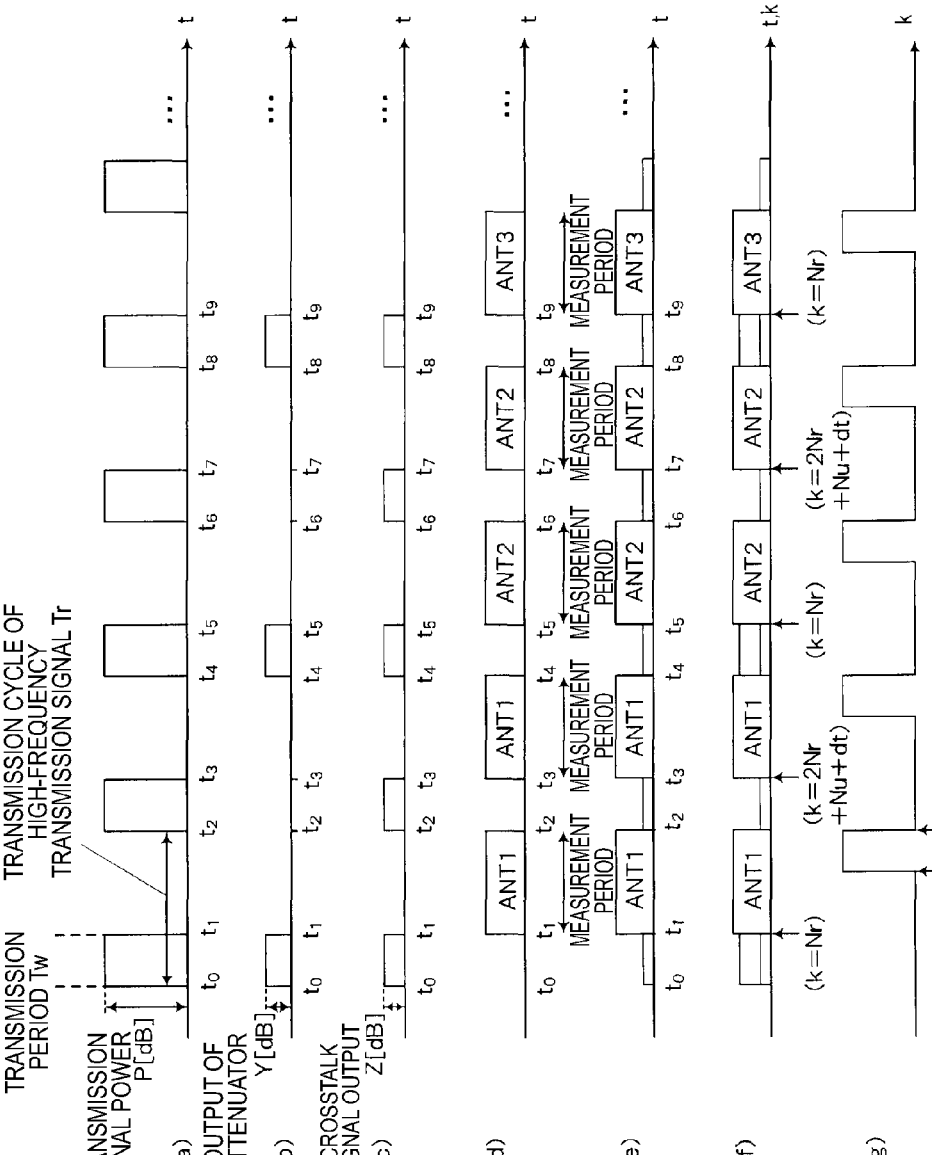

TRANSMISSION SIGNAL POWER P[dB]
TRANSMISSION PERIOD Tw
TRANSMISSION CYCLE OF HIGH-FREQUENCY TRANSMISSION SIGNAL Tr
(a)
OUTPUT OF ATTENUATOR Y[dB]
(b)
CROSSTALK SIGNAL OUTPUT Z[dB]
(c)
(d)
(e)
(f)
(g)
ANT1
ANT2
ANT3
MEASUREMENT PERIOD
(k=Nr)
(k=2Nr +Nu+dt)
(k=2Nr)
(k=Nr+Nu)

FIG. 10

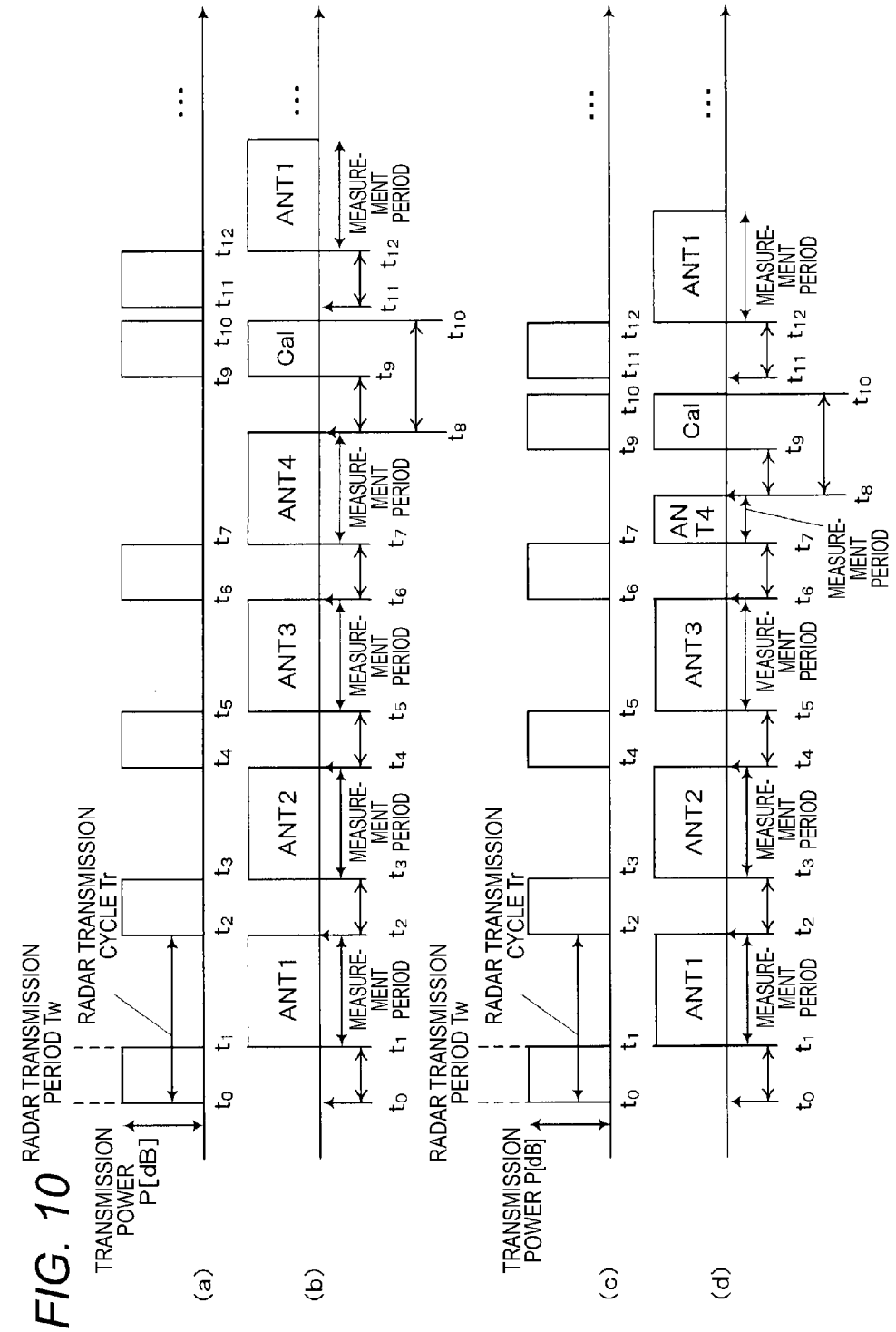

RADAR TRANSMISSION PERIOD Tw
RADAR TRANSMISSION CYCLE Tr
TRANSMISSION POWER P[dB]
(a)
(b)
(c)
(d)
ANT1
ANT2
ANT3
ANT4
Cal
ANT
T4
MEASURE-MENT PERIOD
MEASURE-MENT
t0 t1 t2 t3 t4 t5 t6 t7 t8 t9 t10 t11 t12

FIG. 11

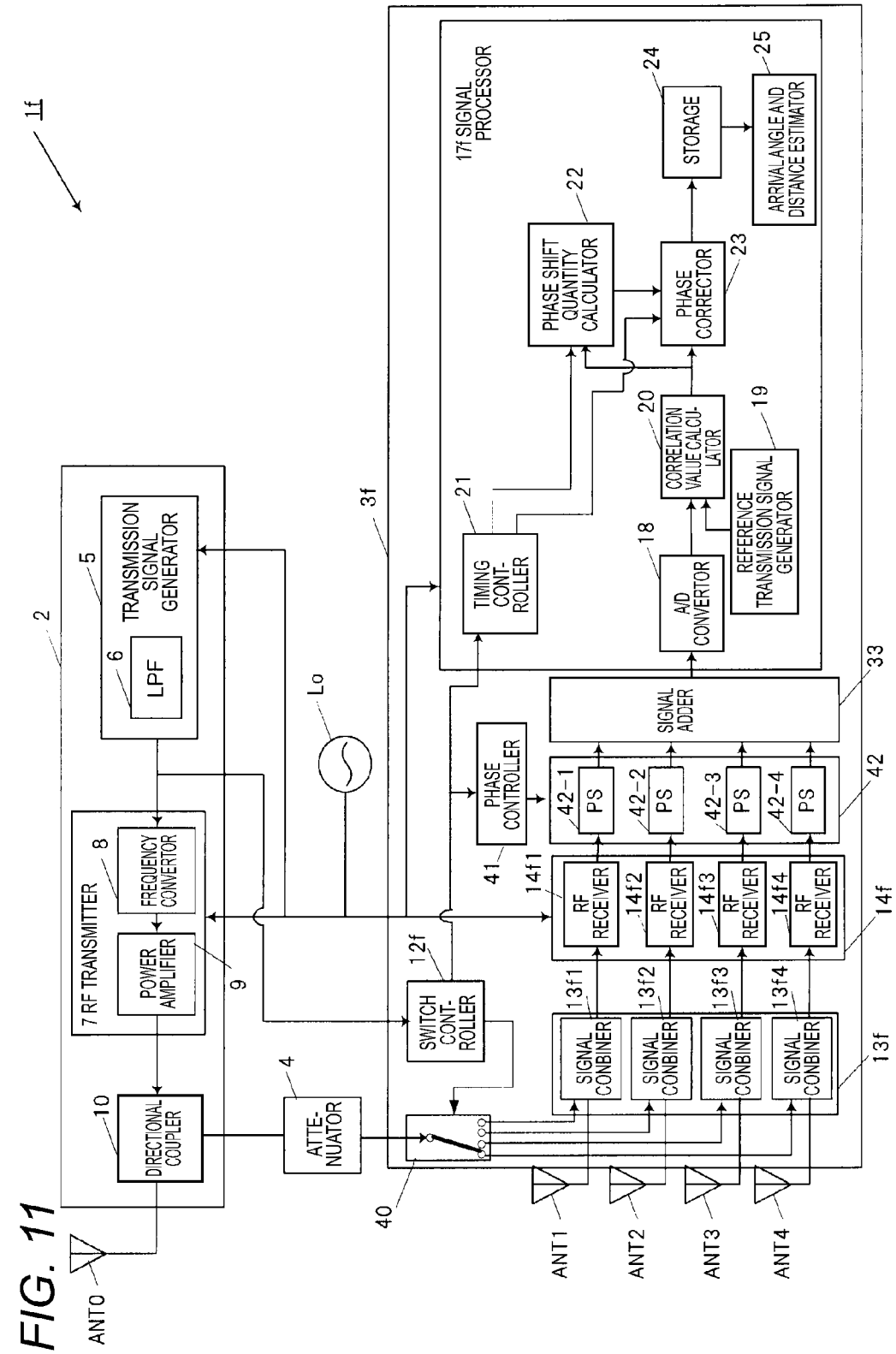

1f
2
3f
4
5
6
7 RF TRANSMITTER
8
9
10
12f
13f
13f1
13f2
13f3
13f4
14f
14f1
14f2
14f3
14f4
17f SIGNAL PROCESSOR
18
19
20
21
22
23
24
25
33
40
41
42
42-1
42-2
42-3
42-4
ANT0
ANT1
ANT2
ANT3
ANT4
Lo
TRANSMISSION SIGNAL GENERATOR
LPF
FREQUENCY CONVERTOR
POWER AMPLIFIER
DIRECTIONAL COUPLER
ATTE-NUATOR
SWITCH CONT-ROLLER
PHASE CONTROLLER
SIGNAL ADDER
PS
RF RECEIVER
SIGNAL CONBINER
TIMING CONT-ROLLER
A/D CONVERTOR
REFERENCE TRANSMISSION SIGNAL GENERATOR
CORRELATION VALUE CALCU-LATOR
PHASE SHIFT QUANTITY CALCULATOR
PHASE CORRECTOR
STORAGE
ARRIVAL ANGLE AND DISTANCE ESTIMATOR

FIG. 12

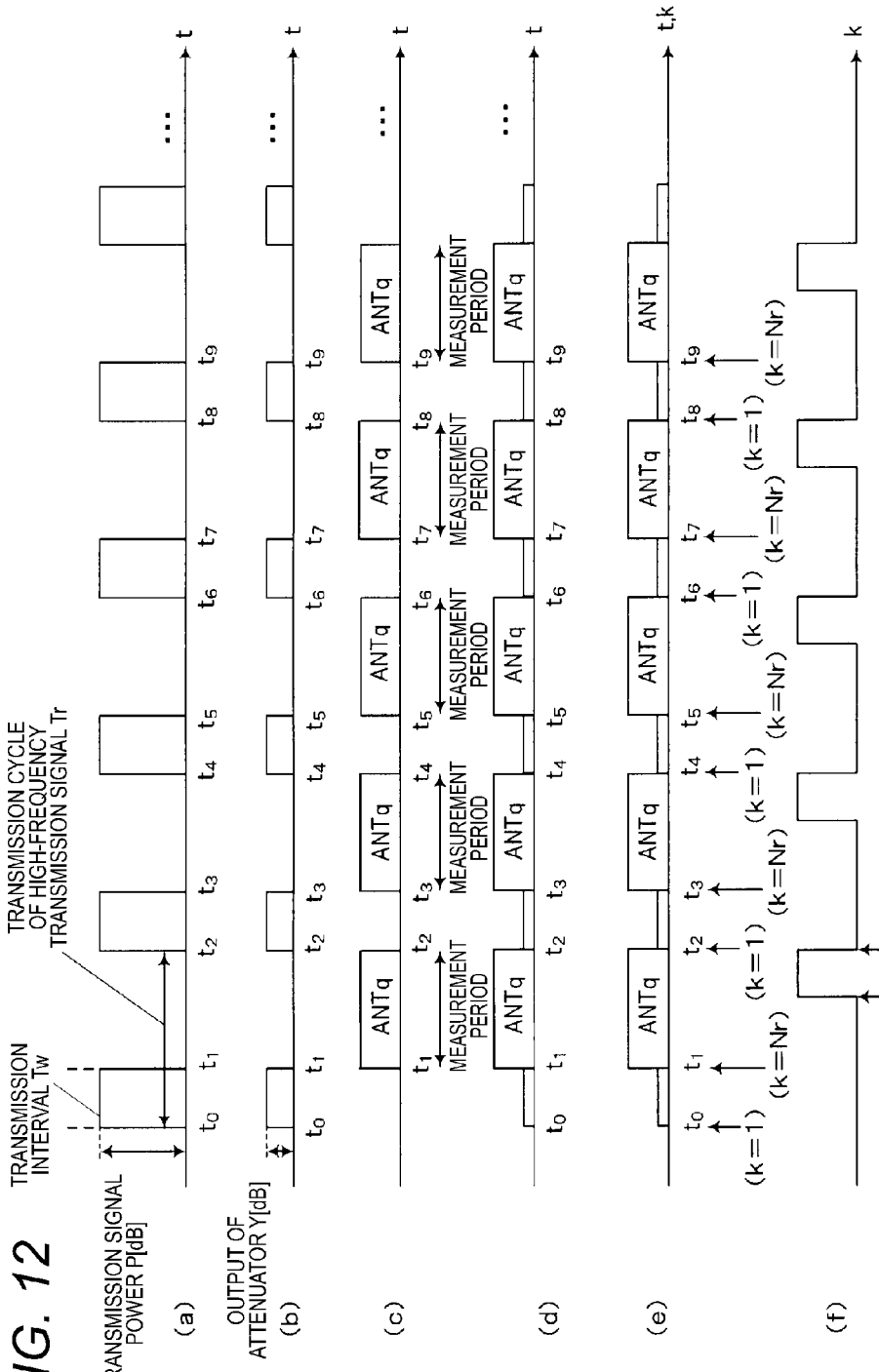
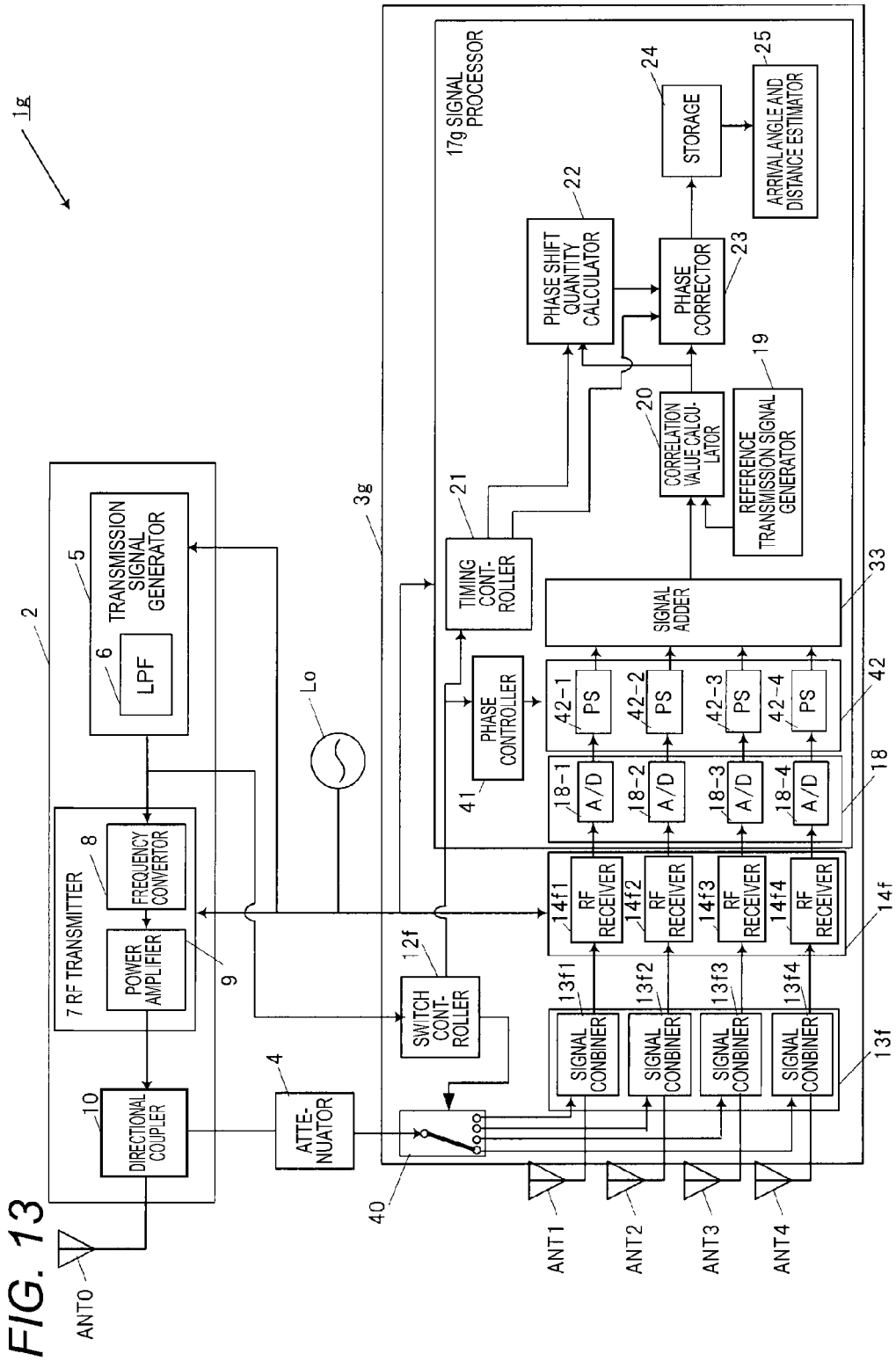

TRANSMISSION SIGNAL POWER P[dB]
TRANSMISSION INTERVAL Tw
TRANSMISSION CYCLE OF HIGH-FREQUENCY TRANSMISSION SIGNAL Tr
(a)
OUTPUT OF ATTENUATOR Y[dB]
(b)
(c)
(d)
(e)
(f)
ANTq
MEASUREMENT PERIOD
(k=1)
(k=Nr)
(k=2Nr)
(k=Nr+Nu)
t
k

FIG. 13


1g
2
3g
4
5
TRANSMISSION SIGNAL GENERATOR
6
LPF
7 RF TRANSMITTER
8
FREQUENCY CONVERTOR
POWER AMPLIFIER
9
10
DIRECTIONAL COUPLER
ATTE-NUATOR
ANT0
Lo
17g SIGNAL PROCESSOR
TIMING CONT-ROLLER
21
PHASE CONTROLLER
41
SWITCH CONT-ROLLER
12f
40
PHASE SHIFT QUANTITY CALCULATOR
22
PHASE CORRECTOR
23
STORAGE
24
ARRIVAL ANGLE AND DISTANCE ESTIMATOR
25
CORRELATION VALUE CALCU-LATOR
20
REFERENCE TRANSMISSION SIGNAL GENERATOR
19
SIGNAL ADDER
33
42-1
42-2
42-3
42-4
PS
42
18-1
18-2
18-3
18-4
A/D
18
14f1
14f2
14f3
14f4
RF RECEIVER
14f
13f1
13f2
13f3
13f4
SIGNAL CONBINER
13f
ANT1
ANT2
ANT3
ANT4

RADAR DEVICE

TECHNICAL FIELD

The present invention relates to a radar device which sequentially receives a signal obtained due to reflection by a target, by a plurality of antennas.

BACKGROUND ART

A radar device radiates radio waves from a point of measurement to space and receives a signal reflected from a target to thereby measure a distance, a direction, etc. from the point of measurement to the target. Development of a radar device capable of detecting not only a car but also a pedestrian or the like as a target by high-resolution measurement using short-wavelength radio waves such as microwaves or millimeter waves has advanced in recent years.

Generally, in a radar device, long-wavelength radio waves are so low in attenuation as to make detection of a distant place possible but are so low in resolution as to make accuracy of target detection low. On the contrary, short-wavelength radio waves are so high in attenuation as to make detection of a distant place difficult because of easy absorption or reflection by water vapor, cloud, rain, etc. contained in air but are so high in resolution as to make accuracy of target detection high. Radar devices disclosed in the following Non-Patent Literature and Patent Literature are known as conventional radar devices.

For example, Non-Patent Literature 1 has disclosed a radar device which scans an antenna mechanically and scans pulse waves or continuous waves electronically with a narrow-angle directional beam to thereby transmit radio waves and receive reflection waves reflected from a target. In the radar device according to Non-Patent Literature 1, the antenna scanning time is required for detecting the target because a single antenna is used for transmission/reception of radio waves.

For example, when a target moving at a high speed is to be detected, it is therefore difficult to detect the target while following the movement of the target because of the necessity of a lot of scans in accordance with required high-resolution measurement.

Non-Patent Literature 2 has disclosed a radar device in which a signal reflected from a target is received by a plurality of antennas disposed spatially and the phase of the received signal is measured without the necessity of a lot of scans so that an arrival angle is estimated with higher resolution than the directivity of each antenna though the beam directivity of each antenna is relatively wide.

According to the radar device of Non-Patent Literature 2, the arrival angle can be estimated by signal processing at thinned-out scanning intervals to thereby improve accuracy of target detection compared with the radar device of Non-Patent Literature 1. Moreover, even when the target is moving at a high speed, the arrival angle can be estimated following the movement of the target.

In Non-Patent literature 2, because a plurality of antennas are however used so that an RF (Radio Frequency) generator for amplifying a signal received by each antenna and down-converting the frequency of the signal to generate a baseband signal and a signal processor for applying A/D (Analog Digital) conversion to the generated baseband signal to calculate a desired arrival angle are provided in accordance with each antenna, the overall configuration of the receiver is complicated and a cost increase is brought.

Patent Literature 1 has disclosed a radar device and a target detecting method in which a switch for selecting one of antennas is provided so that a single transmitter and a single receiver can detect a target while the antenna receiving reflected waves from a target is sequentially selected by the switch. According to Patent Literature 1, simplification in configuration of the radar device can be attained because it is unnecessary to provide the RF generator and the signal processor in the Non-Patent Literature 2 in accordance with each antenna.

However, in Patent Literature 1, to correct a phase shift quantity generated by temporal change of operation in each of the transmitter and the receiver is unconsidered. The phase shift quantity generated by the temporal change is a variable phase shift quantity caused by temporal operation of a local oscillator provided in each of the transmitter and the receiver.

Accordingly, in the configuration of Patent Literature 1, a VCO (Voltage Controlled Oscillator) is connected only to the transmitter even if a reference signal is used in common for driving the local oscillators in the transmitter and the receiver. For this reason, PLL (Phase Locked Loop) circuits provided in the local oscillators respectively operate independently, so that a variable phase shift quantity is caused by temporal operation in between the transmitter and the receiver.

The arrival angle of the target is estimated on the condition that a phase difference dependent on the arrival angle of reflected waves from the target exists between antennas disposed in different positions. For this reason, when a phase shift quantity varying temporally is generated in each sequentially selected antenna and mixed with the signal received by the antenna, accuracy of phase detection according to each antenna deteriorates so that accuracy of target measurement deteriorates.

Moreover, Patent Literature 2 has disclosed a phase calibration device of an active phased array radar which switches a transmission signal as an input signal through a directional coupler and inputs the signal to the reception side as a reference signal in phase calibration.

However, in Patent Literature 2, because a process of distributing a part of the transmission signal through the directional coupler and inputting it to the reception side is performed by a switch, it is necessary to use the switch to notify the reception side of the output timing of the transmission signal whenever the transmission signal is transmitted. As a result, the process applied to the switch is complicated so that the overall configuration of the device is complicated.

However, in a configuration that a mechanism of inputting a part of the transmission signal to the reception side through the directional coupler in Patent Literature 2 is provided between the transmitter and the receiver in Patent Literature 1, a phase shift quantity temporally generated between the transmitter and the receiver can be measured by transmitting an attenuated signal of the transmission signal to the receiver even when the phase shift quantity is generated. Accordingly, there is an inference that deterioration of estimation accuracy of the arrival angle of the target can be reduced to some degree by correcting the measured phase shift quantity.

For example, when a calibration time is provided before a measurement time of a certain radar so that the phase shift quantity is measured in the calibration time, an actually measured phase difference between the transmitter and the receiver can be corrected in a measurement time of an actual radar device based on the phase shift quantity measured in the calibration time.

CITATION LIST

Patent Literature

Patent Literature 1: JP-A-2009-031185
Patent Literature 2: JP-A-10-170633

Non-Patent Literature

Non-Patent Literature 1: Shinichi Yamano and other six persons., "76 GHz Millimeter Wave Automobile Radar Using Single Chip MMIC", Fujitsu Ten Tech. J. Vol. 22, No. 1, pp. 12-19 (June 2004)
Non-Patent Literature 2: JAMES A. Cadzow, "Direction of Arrival Estimation Using Signal Subspace Modeling", IEEE, Vol. 28, pp. 64-79 (1992)

SUMMARY OF INVENTION

Technical Problem

However, when a mechanism in which a part of the transmission signal in Patent Literature 2 is input to the reception side through a directional coupler is provided between the transmitter and the receiver in Patent Literature 1, it is necessary to add a port for the calibration to the switch separately. For this reason, there is a problem that both circuit configurations of the transmitter and the receiver are complicated, and that attenuation of the reception signal increases.

Moreover, because it is necessary to provide calibration time separately in addition to the measurement time in the radar device, there is a problem that the time allowed to be used for measurement as the radar decreases. On the other hand, when cyclic and continuous measurement is designed between the respective antennas inclusive of the calibration time, the measurement time in any one of the antennas is decreased. As a result, there is a problem that the measurement distance range in the antenna decreases.

These problems will be described with reference to FIG. **10**. FIG. **10** shows timing charts in the case where calibration is performed after reception by each antenna in a conventional radar device. In FIG. **10**, (a) and (c) show timing charts of pulse signals which are transmission signals. In FIG. **10**, (b) and (d) show states where a phase shift quantity measurement time for calibration is provided after measurement by each antenna.

In FIG. **10**, assume that Tr [sec] is the transmission cycle of the pulse signal, Tw [sec] is the transmission period of the pulse signal, and P [dB] is the transmission power of the pulse signal. The port of the switch is changed over to an antenna ANT**1** while a pulse signal is transmitted between time t_0 and time t_1, so that measurement by the antenna ANT**1** is performed between time t_1 and t_2. The port of the switch is changed over to an antenna ANT**2** while a pulse signal is transmitted between time t_2 and time t_3, so that measurement by the antenna ANT**2** is performed between time t_3 and time t_4.

The port of the switch is changed over to an antenna ANT**3** while a pulse signal is transmitted between time t_4 and time t_5, so that measurement by the antenna ANT**3** is performed between time t_5 and time t_6. Similarly, the port of the switch is changed over to an antenna ANT**4** while a pulse signal is transmitted between time t_6 and time t_7, so that measurement by the antenna ANT**4** is performed between time t_7 and time t_8.

The port of the switch is changed over to a port for calibration between time t_8 and time t_9, so that calibration is performed between time t_9 and time t_{10}. The port of the switch is changed over to the antenna ANT**1** in the manner between time t_{11} ad time t_{12}, and then the same processing is repeated.

In (b) in FIG. **10**, measurement is performed with an equal measurement time by each of the antennas ANT**1** to ANT**4**. However, a calibration period of time t_8-t_{10} is provided before the transmission time t_{11} of the pulse signal which will be measured by the antenna ANT**1** continuously after the antenna ANT**4**.

The calibration period represented by time t_8-t_{10} is a period which is the sum of a period (time t_8-t_9) for changing the port of the switch over to the calibration port for performing calibration and a calibration execution period (time t_9-t_{10}). Because the calibration period is added as the phase shift quantity measurement time, the time allowed to be used for measurement as the radar decreases.

In (d) in FIG. **10**, measurement is performed with an equal measurement time by each of the antennas ANT**1** to ANT**3**. However, the measurement time in the antenna ANT**4** after the antenna ANT**3** is shorter by the calibration period than the measurement time in the other antennas ANT**1** to ANT**3**. That is, the sum of the measurement period (of time t_7-t_8) in the antenna ANT**4** and the calibration period (of time t_8-t_{10}) is equal to the measurement time in the other antennas ANT**1** to ANT**3**.

Accordingly, in the radar device using a plurality of antennas for performing measurement, when the measurement time in a certain antenna is shorter than the measurement time in any of the other antennas, the measurable distance range in that certain antenna becomes narrow. For this reason, as shown in (d) in FIG. **10**, the measurable distance in the antenna ANT**4** becomes shorter than those in the other antennas ANT**1** to ANT**3**.

The invention is accomplished in consideration of the circumstances in the background art. An object of the invention is to provide a radar device which suppresses deterioration of accuracy in estimation of an arrival angle of a target in such a correction manner that a phase shift quantity of a phase component in a correlation value between a reception signal received by each of reception antennas and a transmission signal is calculated properly while influence on a measurement time or measurement distance range is suppressed.

Solution to Problem

According to the invention, there is provided the radar device which is a radar device for transmitting a high-frequency transmission signal intermittently in a transmission cycle having a predetermined transmission period and a non-transmission period, receiving a signal reflected by a target by using a plurality of reception antennas, and detecting the target based on the reflected signal, the radar device including: a transmission signal generator which generates a transmission signal in baseband; a RF transmitter which converts the transmission signal generated by the transmission signal generator into a high-frequency transmission signal; a directional coupler which distributes the high-frequency transmission signal converted by the RF transmitter in accordance with a predetermined signal power ratio; a level adjuster which adjusts the high-frequency transmission signal distributed by the directional coupler to a predetermined level; a signal combiner which combines a signal output from the level adjuster and a reception signal received by the reception antennas; a RF receiver which converts the signal combined by the signal combiner into a reception signal in the baseband; a reference transmission signal generator which generates a reference transmission signal the same as the transmission

signal generated by the transmission signal generator; a correlation value calculator which calculates a correlation value between the reference transmission signal generated by the reference transmission signal generator and the reception signal converted by the RF receiver; a phase shift quantity calculator which calculates a phase shift quantity in arbitrary one of the reception antennas based on the correlation value in a reference reception antenna which is specific one of the reception antennas, and the correlation value in any one of the other reception antennas; and a phase corrector which corrects a phase component of the correlation value in the arbitrary reception antenna based on the phase shift quantity calculated by the phase shift quantity calculator.

Advantageous Effects of Invention

According to the radar device according to the invention, deterioration of accuracy in estimation of an arrival angle of a target in such a correction manner that a phase shift quantity of a phase component in a correlation value between a reception signal received by each of reception antennas and a transmission signal is calculated properly while influence on a measurement time or measurement distance range is suppressed.

BRIEF DESCRIPTION OF DRAWINGS

[FIG. **1**] A block diagram illustrating the internal configuration of a radar device according to a first embodiment.

[FIG. **2**] A timing chart concerned with operation of the radar device according to the first embodiment, in which (a) is an explanatory view illustrating a timing chart of a high-frequency transmission signal, (b) is an explanatory view illustrating a timing chart of the high-frequency transmission signal input to a signal combiner, (c) is an explanatory view illustrating a period of measurement by each reception antenna, (d) is an explanatory view illustrating an output of a reception signal from a switch and a period of measurement by each antenna, (e) is an explanatory view illustrating an output from the signal combiner, a period of measurement by each reception antenna and a timing for calculating a phase shift quantity, and (f) is an explanatory view illustrating a period for storing a correlation value between a transmission signal and a reception signal.

[FIG. **3**] A block diagram illustrating the internal configuration of a radar device according to Modification 1 of the first embodiment.

[FIG. **4**] A block diagram illustrating the internal configuration of a radar device according to Modification 2 of the first embodiment.

[FIG. **5**] A block diagram illustrating the internal configuration of a radar device according to Modification 3 of the first embodiment.

[FIG. **6**] A timing chart concerned with operation of the radar device according to Modification 3 of the first embodiment, in which (a) is an explanatory view illustrating a timing chart of a high-frequency transmission signal, (b) is an explanatory view for explaining a timing chart of the high-frequency transmission signal input to a signal combiner, and (c) is an explanatory view illustrating a period of measurement by each reception antenna.

[FIG. **7**] A block diagram illustrating the internal configuration of a radar device according to Modification 4 of the first embodiment.

[FIG. **8**] A block diagram illustrating the internal configuration of a radar device according to a second embodiment.

[FIG. **9**] A timing chart concerned with operation of the radar device according to the second embodiment, in which (a) is an explanatory view illustrating a timing chart of a high-frequency transmission signal, (b) is an explanatory view illustrating a timing chart of the high-frequency transmission signal input to a signal combiner, (c) is an explanatory view illustrating a timing chart of a crosstalk signal caused by direct going of the high-frequency transmission signal to each reception antenna, (d) is an explanatory view illustrating a period of measurement by each reception antenna, (e) is an explanatory view illustrating an output of a reception signal from a switch and a period of measurement by each antenna, (f) is an explanatory view illustrating an output from the signal combiner, a period of measurement by each reception antenna and a timing for calculating a phase shift quantity, and (g) is an explanatory view illustrating a period for storing a correlation value between a transmission signal and a reception signal.

[FIG. **10**] A timing chart in the case where calibration is performed after reception by each antenna in a conventional radar device, in which (a) is an explanatory view illustrating a timing chart of a high-frequency transmission signal, (b) is an explanatory view illustrating a state where a phase shift quantity measurement period for calibration is provided after measurement by each antenna, (c) is an explanatory view illustrating a timing chart of a high-frequency transmission signal, and (d) is an explanatory view illustrating a state where a phase shift quantity measurement period for calibration is provided after measurement by each antenna.

[FIG. **11**] A block diagram illustrating the internal configuration of a radar device according to a third embodiment.

[FIG. **12**] A timing chart concerned with operation of the radar device according to the third embodiment, in which (a) is an explanatory view illustrating a timing chart of a high-frequency transmission signal, (b) is an explanatory view illustrating a timing chart of the high-frequency transmission signal input to a signal combiner from an attenuator, (c) is an explanatory view illustrating a period of measurement by each reception antenna, (d) is an explanatory view illustrating a reception signal output from the signal combiner and a period of measurement by each reception antenna, (e) is an explanatory view illustrating an output from the signal combiner, a period of measurement by each reception antenna and a timing for calculating a phase shift quantity, and (f) is an explanatory view illustrating a period for storing a correlation value between a transmission signal and a reception signal.

[FIG. **13**] A block diagram illustrating the internal configuration of a radar device according to Modification 1 of the third embodiment.

DESCRIPTION OF EMBODIMENTS

Respective embodiments of the invention will be described below with reference to the drawings. Although a radar device according to each of the following embodiments will be described in the case where a single pulse signal is used as an example of a transmission signal, the transmission signal is not limited to the single pulse signal. In the following description, a reception signal received by the radar device is a signal combined from a signal after a high-frequency transmission signal from the radar device is reflected by a target, and a noise signal around the radar device. Incidentally, signal power of the noise signal around the radar device is negligibly lower than the signal power of the signal reflected by the target.

[First Embodiment]

The configuration and operation of a radar device **1** according to a first embodiment will be described with reference to FIGS. **1** and **2**. FIG. **1** is a block diagram illustrating the internal configuration of the radar device **1** according to the first embodiment.

FIG. **2** is a timing chart concerned with operation of the radar device **1**. In FIG. **2**, (a) is an explanatory view illustrating a timing chart of a high-frequency transmission signal. In FIG. **2**, (b) is an explanatory view illustrating a timing chart of the high-frequency transmission signal input to a signal combiner **13** from an attenuator **4**. In FIG. **2**, (c) is an explanatory view illustrating a period of measurement by each of reception antennas ANT**1** to ANT**4**. In FIG. **2**, (d) is an explanatory view illustrating an output of a reception signal from a switch **11** and a period of measurement by each of the reception antennas ANT**1** to ANT**4**.

In FIG. **2**, (e) is an explanatory view illustrating an output from the signal combiner **13**, a period of measurement by each of the reception antennas ANT**1** to ANT**4** and a timing for calculating a phase shift quantity. In FIG. **2**, (f) is an explanatory view illustrating a period for storing a correlation value between a transmission signal and a reception signal.

As shown in FIG. **1**, the radar device **1** has an oscillator Lo, a radar transmitter **2**, a radar receiver **3**, a transmission antenna ANT**0**, reception antennas ANT**1** to ANT**4**, and an attenuator **4**. In the radar device **1** according to the first embodiment, a predetermined intermittent high-frequency transmission signal generated by the radar transmitter **2** is transmitted from the transmission antenna ANT**0**, a signal reflected by a target is received by a reception antenna sequentially selected from the reception antennas ANT**1** to ANT**4**, and the target is detected from the reception signal thus received. Incidentally, the target is an object such as a car or a person to be detected by the radar device **1**. The same thing applies to the following embodiments.

The radar transmitter **2** has a transmission signal generator **5**, a RF transmitter **7**, and a directional coupler **10**. Although the transmission signal generator **5** in FIG. **1** is formed to include an LPF (Low Pass Filter) **6**, the LPF **6** may be formed independent of the transmission signal generator **5**. The RF transmitter **7** has a frequency converter **8**, and a power amplifier **9**.

The transmission signal generator **5** generates a timing clock based on a reference signal generated by the oscillator Lo so that the reference signal is multiplied by a predetermined number. The transmission signal generator **5** cyclically generates a transmission signal r(n) of a baseband formed from a pulse train having a plurality of pulses based on the generated timing clock. The transmission signal generator **5** outputs a transmission signal r(n) of a predetermined limited band to the RF transmitter **7** through the LPF **6**.

Here, the parameter n expresses discrete time. As the transmission signal generated by the transmission signal generator **5**, not a continuous signal but a pulse train signal is used. Incidentally, the transmission signal is not limited to the pulse train signal. For example, a single pulse signal or a pulse signal including a plurality of pulse trains or a modulated signal due to frequency modulation or phase modulation of the single pulse signal or the pulse signal including a plurality of pulse trains may be used.

As shown in (a) of FIG. **2**, assume that Nr [pieces] of samples are provided as a baseband transmission signal r(n) in a period Tw [sec] of presence of a high-frequency transmission signal transmitted from the transmission antenna ANT**0** whereas Nu [pieces] of samples are provided as a baseband transmission signal r(n) in a period (Tr−Tw) [sec] of absence of the high-frequency transmission signal. The parameter Tr is a transmission cycle [sec] of the high-frequency transmission signal transmitted from the transmission antenna ANT**0**.

The RF transmitter **7** generates a timing clock based on a reference signal generated by the oscillator Lo so that the reference signal is multiplied by a predetermined number. The RF transmitter **7** operates based on the generated reference signal. Specifically, the frequency converter **8** receives as an input a transmission signal r(n) generated by the transmission signal generator **5** and frequency-converts the input baseband transmission signal r(n) to generate a carrier frequency band high-frequency transmission signal. The frequency converter **8** outputs the generated high-frequency transmission signal to the power amplifier **9**.

The power amplifier **9** receives the output high-frequency transmission signal, amplifies the signal power of the input high-frequency transmission signal to predetermined signal power P [dB] and outputs the predetermined signal power P [dB] to the transmission antenna ANT**0**. The amplified high-frequency transmission signal is transmitted so as to be radiated to space through the directional coupler **10** and the transmission antenna ANT**0**.

The directional coupler **10** outputs the high-frequency transmission signal output from the power amplifier **9** of the RF transmitter **7** to the transmission antenna ANT**0**, distributes the high-frequency transmission signal in accordance with a predetermined signal power ratio and outputs the distributed high-frequency transmission signal to the attenuator **4**.

The transmission antenna ANT**0** performs transmission so that the high-frequency transmission signal output from the RF transmitter **7** is radiated to space. As shown in (a) of FIG. **2**, the high-frequency transmission signal is transmitted during a period of time t_0-t_1, during a period t_2-t_3, during a period of time t_4-t_5, during a period of time t_6-t_7 and during a period of time t_8-t_9 but not transmitted during a period of time t_1-t_2, during a period of time t_3-t_4, during a period of time t_5-t_6 and during a period of time t_7-t_8. After time t_9, transmission of the high-frequency transmission signal is repeated in the same manner.

As shown in (b) of FIG. **2**, the attenuator **4** attenuates the signal power of the high-frequency transmission signal output from the directional coupler **10** to predetermined signal power Y [dB] in sync with the transmission period of the high-frequency transmission signal. The attenuator **4** outputs the attenuated high-frequency transmission signal to the signal combiner **13** of the radar receiver **3**.

The radar receiver **3** has four reception antennas ANT**1** to ANT**4**, a switch **11**, a switch controller **12**, a signal combiner **13**, a RF receiver **14**, and a signal processor **17**. The RF receiver **14** has a power amplifier **15**, and a frequency converter **16**. The signal processor **17** has an A/D converter **18**, a reference transmission signal generator **19**, a correlation value calculator **20**, a timing controller **21**, a phase shift quantity calculator **22**, a phase corrector **23**, a storage **24**, and an arrival angle and distance estimator **25**.

The reception antennas ANT**1** to ANT**4** form an array antenna of four reception antennas ANT**1** to ANT**4**. The reception antennas ANT**1** to ANT**4** receive a signal obtained due to reflection of the high-frequency transmission signal transmitted from the radar transmitter **2** by a target and a noise signal around the radar device **1** as a reception signal. Although description will be made in the case where the number of elements of the array antenna in the radar device **1** according to the first embodiment is 4 as shown in FIG. **1**, the number of elements of the array antenna is not limited to 4.

The switch **11** is provided with switching ports corresponding to the reception antennas ANT**1** to ANT**4** so that the switch **11** is connected to the four reception antennas ANT**1** to ANT**4**.

In the switch **11**, the respective switching ports corresponding to the four reception antennas ANT**1** to ANT**4** are changed sequentially under control of the switch controller **12**. By this change, a single switching port is selected so that the switch **11** is connected to a reception antenna ANTs corresponding to the switching port. The parameter s satisfies s=1 to 4. The switch **11** outputs a reception signal received by the selected reception antenna ANTs to the signal combiner **13**.

The switch controller **12** controls the switch **11** so that the four reception antennas ANT**1** to ANT**4** are changed sequentially in a cycle of an integer multiple N (N: integer) of the transmission cycle Tr [sec] of the high-frequency transmission signal. In the first embodiment, as shown in (c) of FIG. **2**, the switch controller **12** controls the switch **11** so that the four reception antennas ANT**1** to ANT**4** are changed sequentially in the same cycle (N=1) as the transmission cycle Tr [sec] of the high-frequency transmission signal.

Specifically, as shown in (c) of FIG. **2**, the switch controller **12** selects the reception antenna ANT**1** during a period of time t_0-t_1. Moreover, the switch controller **12** controls the switch **11** so that a reception signal received by the reception antenna ANT**1** is output to the signal combiner **13** during a period of time t_1-t_2. Incidentally, the period of time t_1-t_2 is a measurement period in which a signal is received by the reception antenna ANT**1** (parameter s=1).

The switch controller **12** selects the reception antenna ANT**2** during a period of time t_2-t_3. Moreover, the switch controller **12** controls the switch **11** so that a reception signal received by the reception antenna ANT**2** is output to the signal combiner **13** during a period of time t_3-t_4. Incidentally, the period of time t_3-t_4 is a measurement period in which a signal is received by the reception antenna ANT**2** (parameter s=2).

The switch controller **12** selects the reception antenna ANT**3** during a period of time t_5-t_6. Moreover, the switch controller **12** controls the switch **11** so that a reception signal received by the reception antenna ANT**3** is output to the signal combiner **13** during a period of time t_4-t_5. Incidentally, the period of time t_5-t_6 is a measurement period in which a signal is received by the reception antenna ANT**3** (parameter s=3).

The switch controller **12** selects the reception antenna ANT**4** during a period of time t_6-t_7. Moreover, the switch controller **12** controls the switch **11** so that a reception signal received by the reception antenna ANT**4** is output to the signal combiner **13** during a period of time t_7-t_8. Incidentally, the period of time t_7-t_8 is a measurement period in which a signal is received by the reception antenna ANT**4** (parameter s=4).

Incidentally, as shown in (d) of FIG. **2**, the reception signal output from the switch **11** in each of periods of times t_0-t_1, t_2-t_3, t_4-t_5, t_6-t_7 and t_8-t_9 is a noise signal around the radar device **1**.

The reception signal output from the switch **11** in each of periods of times t_1-t_2, t_3-t_4, t_5-t_6 and t_7-t_8 is a signal combined from the noise signal and a reception signal (not shown) corresponding to each of the measurement periods (of times t_1-t_2, t_3-t_4, t_5-t_6 and t_7-t_8). However, the noise signal is negligibly lower than the reception signal. The same thing applies to the following embodiments.

The signal combiner **13** combines a signal from the high-frequency transmission signal output from the attenuator **4** and the reception signal output from the switch **11**, and outputs the combined signal to the power amplifier **15** of the RF receiver **14**. Here, when the average signal power of the reception signal output from the switch **11** is Z [dB], the signal power of the combined signal output from the signal combiner **13** is (Y+Z) [dB].

Incidentally, it is preferable that the signal power Y [dB] of the high-frequency transmission signal output from the attenuator **4** is attenuated so as to be sufficiently higher (e.g. 3 [dB] to 10 [dB]) than the signal power received by the reception antenna ANTs in a period (of e.g. time t_0-t_1 etc.) in which the switch controller **12** changes the switching port of the switch **11**.

When there are side lobes in autocorrelation characteristic of the high-frequency transmission signal, it is preferable that the attenuator **4** attenuates the signal power of the high-frequency transmission signal output from the directional coupler **10** to such signal power that the level of the side lobes has no influence on the measurement period of the radar device **1**.

Moreover, it is preferable that the timing in which the high-frequency transmission signal attenuated by the attenuator **4** is combined by the signal combiner **13** is synchronized with the transmission cycle Tw [sec] of the high-frequency transmission signal transmitted from the radar transmitter **2** and is kept without any time lag. The same thing applies to the following embodiments.

As shown in (e) of FIG. **2**, the combined signal output from the signal combiner **13** in each of periods of times t_0-t_1, t_2-t_3, t_4-t_5, t_6-t_7 and t_8-t_9 is a signal combined from a noise signal around the radar device **1** and the high-frequency transmission signal output from the attenuator **4**.

On the other hand, the combined signal output from the signal combiner **13** in each of periods of times t_1-t_2, t_3-t_4, t_5-t_6 and t_7-t_8 is a signal combined from the noise signal and a reception signal (not shown) corresponding to each of measurement periods (of times t_1-t_2, t_3-t_4, t_5-t_6 and t_7-t_8).

The RF receiver **14** generates a timing clock based on a reference signal generated by the oscillator Lo so that the reference signal is multiplied by a predetermined number. The RF receiver **14** operates based on the generated timing clock. Specifically, the power amplifier **15** receives as an input the combined signal combined by the signal combiner **13**, amplifies the signal power of the input combined signal to predetermined signal power, and outputs the combined signal to the frequency converter **16**.

The frequency converter **16** receives as an input the combined signal output from the power amplifier **15**, frequency-converts the input combined signal and phase-shifts the phase component of part of the combined signal by 90 [degrees] based on quadrature detection to thereby generate a baseband reception signal composed of an in-phase signal and a quadrature signal. The frequency converter **16** outputs the generated reception signal to the signal processor **17**.

The A/D converter **18** performs sampling at discrete time k for the baseband reception signal composed of the in-phase signal and the quadrature signal generated by the frequency converter **16** to thereby convert the reception signal into digital data.

Here, the reception signal at discrete time k in the reception antenna ANTs is expressed as a complex signal of a complex number $x(s,k)=I(s,k)+jQ(s,k)$ in which I(s,k) is the in-phase signal of the reception signal and Q(s,k) is the quadrature signal of the reception signal. Incidentally, the parameter j is an imaginary unit.

Moreover, the parameter k expresses discrete time corresponding to the number of samples of the baseband transmis-

sion signal r(n) included in the high-frequency transmission signal. In the first embodiment, the timing of switching to the reception antenna ANTs is set at k=1 and at k=1 to (Nr+Nu). Accordingly, as shown in (e) of FIG. **2**, the parameter k satisfies k=1 at the timing of time t_0, time t_2, time t_4, time t_6 and time t_8. In addition, the parameter k satisfies k=Nr at the timing of time t_1, time t_3, time t_5, time t_7 and time t_9.

The reference transmission signal generator **19** generates a timing clock based on a reference signal generated by the oscillator Lo in the same manner as the transmission signal generator **5** in sync with the operation of the transmission signal generator **5** so that the reference signal is multiplied by a predetermined number. The reference transmission signal generator **19** cyclically generates a reference transmission signal r(n) of the same baseband as the transmission signal generated by the transmission signal generator **5**, based on the generated reference signal. The reference transmission signal generator **19** outputs the generated reference transmission signal r(n) to the correlation value calculator **20**.

The correlation value calculator **20** calculates a correlation value AC(s,k) between the complex signal x(s,k) of the reception signal received by the reception antenna ANTs and the reference transmission signal r(n) output from the reference transmission signal generator **19**. Assume now that a sliding correlation value as represented by the expression (1) is calculated as the correlation value.

The sliding correlation value AC(s,k) is a correlation value at discrete time k between the reception signal (including a reflected signal and a noise signal) received by the reception antenna ANTs and the reference transmission signal. The asterisk (*) in the expression (1) expresses a complex conjugate operator. The sliding correlation value AC(s,k) is calculated in periods at k=1 to (Nr+Nu). That is, the sliding correlation value AC(s,k) is calculated in periods of times t_0-t_2, t_2-t_4, t_4-t_6, t_6-t_8, etc.

[Expression 1]

$$AC(s,k)=\sum_{m=1}^{Nr} x(s,k+m-1)r^*(m) \quad (1)$$

Incidentally, when the transmission signal generated by the transmission signal generator **5** is a baseband signal r(n) composed of real numbers, the signal r(n) is used as the reference transmission signal in the calculation of the sliding correlation value AC(s,k). On the other hand, when the transmission signal generated by the transmission signal generator **5** is a baseband signal r(n) composed of an in-phase signal and a quadrature signal, a complex conjugate value of the signal r(n) is used.

The timing controller **21** regards the timing k_0 of completion of the period Tw [sec] (transmission period) of presence of the high-frequency transmission signal transmitted from the transmission antenna ANT**0** as the timing of completion of calculation of the sliding correlation value AC(s,k_0) by the correlation value calculator **20**, and notifies the phase shift quantity calculator **22** of the timing information of completion of calculation of the sliding correlation value AC(s,k_0).

As shown in (c) and (e) of FIG. **2**, the timing k_0 of completion of the period Tw [sec] of presence of the high-frequency transmission signal transmitted from the transmission antenna ANT**0** and the timing of completion of calculation of the sliding correlation value AC(s,k_0) by the correlation value calculator **20** are the same times as the times t_1, t_3, t_5, t_7 and t_9 and correspond to discrete time k_0=Nr.

The timing controller **21** notifies the phase corrector **23** of the timing information for indicating that the sliding correlation value AC(s,k) corrected by the phase corrector **23** is stored in the storage **24** with respect to the sliding correlation value AC(s,k) between the complex signal x(s,k) of the reception signal received by the reception antenna ANTs and the reference transmission signal r(n) output from the reference transmission signal generator **19**. However, discrete time k satisfies k=2Nr to (Nr+Nu) (see (f) of FIG. **2**).

Incidentally, the discrete time k can be also set in a range of k=(Nr+1) to (Nr+Nu). However, the start timing of discrete time k at which the sliding correlation value AC(s,k) is stored in the storage **24** is determined in the timing controller **21** not at k=Kr but at k=2Nr on the assumption that not a target nearest to the radar device **1** but a target at a predetermined distance [m] or farther from the radar device **1** is detected.

Accordingly, because it is not necessary to consider that the intensive reception level is received from a target nearest to the radar device **1** without distortion, the dynamic range in the radar receiver **3** of the radar device **1** can be reduced. With respect to the start timing of discrete time k at which the sliding correlation value AC(s,k) is stored in the storage **24**, in the timing controller **21**, the same thing applies to the flowing embodiments.

The phase shift quantity calculator **22** extracts a sliding correlation value AC(s,Nr) in the reception antenna ANTs and a sliding correlation value AC(s_0,Nr) in the reference reception antenna ANTs$_0$ (which will be described later) based on the timing information given from the timing controller **21** for indicating the completion of calculation of the sliding correlation value.

Here, a reception antenna ANTs$_0$ which is one of the four reception antennas ANT**1** to ANT**4** shown in FIG. **1** and which is provided as a reference for calculating a phase shift quantity is referred to as reference reception antenna. Assume further that the sliding correlation value AC(s_0,Nr) in the reference reception antenna ANTs$_0$ and the sliding correlation value AC(s,Nr) in the reception antenna ANTs have been already calculated by the correlation value calculator **20**.

The phase shift quantity calculator **22** calculates a phase shift quantity $\Delta\theta(s)$ in the reception antenna ANTs in accordance with the expression (2) based on the sliding correlation value AC(s,Nr) in the reception antenna ANTs and the sliding correlation value AC(s_0,Nr) in the reference reception antenna ANTs$_0$. The phase shift quantity calculator **22** outputs the calculated phase shift quantity $\Delta\theta(s)$ to the phase corrector **23**.

[Expression 2]

$$\Delta\theta(s)=\angle[AC(s,Nr)AC^*(s_0,Nr)] \quad (2)$$

Each of the parameter s and the parameter s_0 expresses the number of reception antennas. Each of s and s_0 expresses any one of 1, 2, 3 and 4. The asterisk (*) expresses a complex conjugate operator. $\angle[x]$ expresses a phase component of a complex number x and is represented by the expression (3).

[Expression 3]

$$\angle[x]=\tan^{-1}(Im[x]/Re[x]) \quad (3)$$

Incidentally, Im[x] expresses an imaginary part of the complex number and Re expresses a real part of the complex number.

The phase corrector **23** corrects the phase component of the sliding correlation value AC(s,k) in the reception antenna ANTs calculated by the correlation value calculator **20** in

accordance with the expression (4) based on the phase shift quantity output from the phase shift quantity calculator **22**.

[Expression 4]

$$\angle[AC(s,k)]-\Delta\theta(s) \quad (4)$$

The phase corrector **23** stores the sliding correlation value (see the expression (5)) having the corrected phase component in the reception antenna ANTs at discrete time of k=2Nr to (Nr+Nu) in the storage **24** based on the timing information output from the timing controller **21** for indicating that the corrected sliding correlation value is stored.

[Expression 5]

$$|AC(s,k)|\exp(j\{\angle[AC(s,k)]-\Delta\theta(s)\}) \quad (5)$$

The arrival angle and distance estimator **25** performs calculation to estimate the arrival angle of the target and the distance to the target based on the sliding correlation value AC(s,k) having the corrected phase component in each reception antenna ANTs stored in the storage **24**. The calculation to estimate the arrival angle by the arrival angle and distance estimator **25** is a technique which has become publicly known. For example, this technique can be achieved by referring to Non-Patent Literature 2 which has been described above. Moreover, the calculation to estimate the distance to the target by the arrival angle and distance estimator **25** can be achieved by referring to Reference Non-Patent Literature 1 which will be described below.

(Reference Non-Patent Literature 1) J. J. BUSSGANG, et al., "A Unified Analysis of Range Performance of CW, Pulse, ad Pulse Doppler Radar", Proceedings of the IRE, Vol. 47, Issue 10, pp. 1753-1762 (1959)

For example, the arrival angle and distance estimator **25** calculates reception signal power in the reception antenna based on the correlation value having the corrected phase component in the reception antenna ANTs with respect to the arrival angle of the target. The reception signal power includes the phase component at the arrival angle of the target. The arrival angle and distance estimator **25** estimates the angle of the phase component in the case where the reception signal power takes a maximum value as the arrival angle of the target.

For example, the arrival angle and distance estimator **25** estimates the distance to the target based on the time difference between the discrete time in the case where the correlation value takes a maximum value and the transmission time of the high-frequency transmission signal based on the correlation value having the corrected phase component in the reception antenna ANTs with respect to the distance to the target.

As described above, in accordance with the radar device **1** according to the first embodiment, a phase shift quantity of a phase component in a correlation value between a reception signal received by each of reception antennas and a transmission signal can be calculated properly as measurement performance of the radar device while, for example, influence on the measurement time or measurement distance range is suppressed.

Moreover, the radar device **1** can correct the phase component of the correlation value in each reception antenna ANTs based on the properly calculated phase shift quantity to thereby suppress deterioration of accuracy of measurement of the arrival angle of the target and the distance to the target.

Moreover, in accordance with the radar device **1**, it is unnecessary to provide any switching port for calibration in the switch **11**, compare with the conventional radar device. Accordingly, the radar device **1** can perform calibration concerned with the phase for the reception antenna ANTs in accordance with transmission of the high-frequency transmission signal, so that accurate measurement can be performed compared with the conventional radar device.

Moreover, in accordance with the radar device **1**, because the transmission signal for calibration is the same as the transmission signal for measurement, execution can be made without addition of any correlation calculator for calibration to the signal processor **17**, so that execution can be made without complication of circuit configuration.

[Modification 1 of First Embodiment]

In the first embodiment, each reception antenna ANTs is directly connected to the switch **11** so that the reception signal by the reception antenna ANTs is input to the switch **11**. In Modification 1 of the first embodiment, the frequency of the reception signal is converted into a baseband by the frequency converter of the RF receiver so that the reception signal is input to the switch.

FIG. **3** is a block diagram illustrating the internal configuration of a radar device **1***a* according to Modification 1 of the first embodiment. Although the difference in configuration and operation of Modification 1 of the first embodiment from the radar device **1** according to the first embodiment will be described with reference to FIG. **3**, description of the same configuration and operation as those of the radar device **1** according to the first embodiment will be omitted.

In FIG. **3**, a radar receiver **3***a* has four reception antennas ANT**1** to ANT**4**, a signal combiner **13***a*, a RF receiver **14***a*, a switch **11***a*, a switch controller **12**, and a signal processor **17**.

The signal combiner **13***a* has a signal combiner **13***a***1** to which a reception signal by the reception antenna ANT**1** is input, a signal combiner **13***a***2** to which a reception signal by the reception antenna ANT**2** is input, a signal combiner **13***a***3** to which a reception signal by the reception antenna ANT**3** is input, and a signal combiner **13***a***4** to which a reception signal by the reception antenna ANT**4** is input. A high-frequency transmission signal attenuated by an attenuator **4** is input to the signal combiners **13***a***1** to **13***a***4**.

Each of the signal combiners **13***a***1** to **13***a***4** combines a signal from a reception signal by corresponding one of the reception antennas ANT**1** to ANT**4** connected to the signal combiners **13***a***1** to **13***a***4** respectively and the high-frequency transmission signal attenuated by the attenuator **4**, and outputs the combined signal to corresponding one of RF receivers **14***a***1** to **14***a***4** of the RF receiver **14***a*, similarly to the signal combiner **13** according to the first embodiment.

The RF receiver **14***a* has a RF receiver **14***a***1** to which the combined signal output from the signal combiner **13***a***1** is input, a RF receiver **14***a***2** to which the combined signal output from the signal combiner **13***a***2** is input, a RF receiver **14***a***3** to which the combined signal output from the signal combiner **13***a***3** is input, and a RF receiver **14***a***4** to which the combined signal output from the signal combiner **13***a***4** is input.

Each of the RF receivers **14***a***1** to **14***a***4** has the same configuration as that of the RF receiver **14** in the first embodiment. Like the RF receiver **14**, each of the RF receivers **14***a***1** to **14***a***4** receives and amplifies the combined signal output from corresponding one of the signal combiners **13***a***1** to **13***a***4**, and frequency-converts the amplified combined signal to generate a baseband reception signal composed of an in-phase signal and a quadrature signal. The reception signal generated by each of the RF receivers **14***a***1** to **14***a***4** is input to the switch **11***a*.

The switch **11***a* is provided with switching ports corresponding to the RF receivers **14***a***1** to **14***a***4** respectively so that the switch **11***a* is connected to each of the RF receivers **14***a***1** to **14***a***4**.

The switch **11***a* sequentially changes the switching ports corresponding to the RF receivers **14***a***1** to **14***a***4** under control of the switch controller **12** so that a single switching port is selected and the switch **11***a* is connected to the RF receiver **14***a* corresponding to the switching port.

The switch **11***a* outputs a baseband reception signal generated by the selected RF receiver **14***a* to the signal processor **17** by changing the switching port. Processing after that is the same as in the first embodiment.

As described above, in the radar device **1***a* according to Modification 1 of the first embodiment, because the signal combiners **13***a* and the RF receivers **14***a* are provided in accordance with the reception antennas ANT**1** to ANT**4**, the configuration of the radar receiver **3***a* is complicated compared with the radar device **1** according to the first embodiment.

However, in the switch **11***a*, the switching port is changed in accordance with the baseband reception signal generated by the RF receiver **14***a*. For this reason, power loss of the reception signal at the time of changing in the switch **11***a* can be reduced compared with the radar device **1** according to the first embodiment in which the switching port is changed in accordance with the high-frequency reception signal.

Hence, in accordance with the radar device **1***a* according to Modification 1 of the first embodiment, SNR (Signal Noise Ratio) at reception of a signal reflected by a target in a measurement period can be improved compared with the radar device **1** according to the first embodiment. As a result, in accordance with the radar device **1***a*, accuracy of measurement of the target in the measurement period can be improved.

[Modification 2 of First Embodiment]

In the first embodiment, each reception antenna ANTs is directly connected to the switch **11** so that a reception signal by each reception antenna ANTs is input to the switch **11**. In Modification 2 of the first embodiment, the frequency of a reception signal is converted into an intermediate frequency band as an IF (Intermediate Frequency) band by the frequency converter of the RF receiver so that the reception signal is input to the switch.

FIG. **4** is a block diagram illustrating the internal configuration of a radar device **1***b* according to Modification 2 of the first embodiment. Although the difference in configuration and operation of Modification 2 of the first embodiment from the radar device **1** according to the first embodiment will be described with reference to FIG. **4**, description of the same configuration and operation as those of the radar device **1** according to the first embodiment will be omitted.

In FIG. **4**, a radar receiver **3***b* has four reception antennas ANT**1** to ANT**4**, a signal combiner **13***b*, a RF receiver **14***b*, a switch **11***b*, a switch controller **12**, an IF receiver **26**, and a signal processor **17**.

The signal combiner **13***b* has a signal combiner **13***b***1** to which a reception signal by the reception antenna ANT**1** is input, a signal combiner **13***b***2** to which a reception signal by the reception antenna ANT**2** is input, a signal combiner **13***b***3** to which a reception signal by the reception antenna ANT**3** is input, and a signal combiner **13***b***4** to which a reception signal by the reception antenna ANT**4** is input. A high-frequency transmission signal attenuated by an attenuator **4** is input to the signal combiners **13***b***1** to **13***b***4**.

Like the signal combiner **13** in the first embodiment, each of the signal combiners **13***b***1** to **13***b***4** combines a signal from a reception signal by corresponding one of the reception antennas ANT**1** to ANT**4** connected to the signal combiners **13***b***1** to **13***b***4** respectively and the high-frequency transmission signal attenuated by the attenuator **4**, and outputs the combined signal to corresponding one of RF receivers **14***b***1** to **14***b***4** of the RF receiver **14***b*.

The RF receiver **14***b* has a RF receiver **14***b***1** to which the combined signal output from the signal combiner **13***b***1** is input, a RF receiver **14***b***2** to which the combined signal output from the signal combiner **13***b***2** is input, a RF receiver **14***b***3** to which the combined signal output from the signal combiner **13***b***3** is input, and a RF receiver **14***b***4** to which the combined signal output from the signal combiner **13***b***4** is input.

Each of the RF receivers **14***b***1** to **14***b***4** has the same configuration as that of the RF receiver **14** in the first embodiment. Like the RF receiver **14**, each of the RF receivers **14***b***1** to **14***b***4** receives and amplifies the combined signal output from corresponding one of the signal combiners **13***b***1** to **13***b***4**, and frequency-converts the amplified combined signal to generate an intermediate frequency band reception signal. The reception signal generated by each of the RF receivers **14***b***1** to **14***b***4** is input to the switch **11***b*.

The switch **11***b* is provided with switching ports corresponding to the RF receivers **14***b***1** to **14***b***4** respectively so that the switch **11***b* is connected to each of the RF receivers **14***b***1** to **14***b***4**. The switch **11***b* sequentially changes the switching ports corresponding to the four RF receivers **14***b***1** to **14***b***4** under control of the switch controller **12**. By this changing, a single switching port is selected so that the switch **11***b* is connected to the RF receiver **14***b* corresponding to the switching port. The switch **11***b* outputs an intermediate frequency band reception signal generated by the selected RF receiver **14***b* to the IF receiver **26** by changing the switching port.

The IF receiver **26** has a power amplifier **27** and a frequency converter **28**. The IF receiver **26** generates a timing clock based on a reference signal generated by an oscillator Lo so that the reference signal is multiplied by a predetermined number. The IF receiver **26** operates based on the generated timing clock. Specifically, the power amplifier **27** receives as an input the intermediate frequency band reception signal output from the switch **11***b*, amplifies the signal power of the input reception signal to predetermined signal power, and outputs the reception signal to the frequency converter **28**.

The frequency converter **28** receives as an input the reception signal output from the power amplifier **27**, frequency-converts the input reception signal and phase-shifts the phase component of part of the reception signal by 90 [degrees] based on quadrature detection to thereby generate a baseband reception signal composed of an in-phase signal and a quadrature signal. The frequency converter **28** outputs the generated reception signal to the signal processor **17**. Processing after that is the same as in the first embodiment.

As described above, in the radar device **1***b* according to Modification 2 of the first embodiment, because the signal combiners **13***b* and the RF receivers **14***b* are provided in accordance with the reception antennas ANT**1** to ANT**4**, the configuration of the radar receiver **3***b* is complicated compared with the radar device **1** according to the first embodiment. However, in the switch **11***b*, the switching port is changed in accordance with the intermediate frequency band reception signal generated by the RF receiver **14***b*. For this reason, power loss of the reception signal at the time of changing in the switch **11***b* can be reduced compared with the radar device **1** according to the first embodiment in which the switching port is changed in accordance with the high-frequency reception signal.

Hence, in accordance with the radar device **1***b* according to Modification 2 of the first embodiment, SNR at reception of a signal reflected by a target in a measurement period can be improved compared with the radar device **1** according to the first embodiment. As a result, in accordance with the radar device **1***b*, accuracy of measurement of the target in the measurement period can be improved.

[Modification 3 of First Embodiment]

The first embodiment has been described to the effect that a phase shift quantity in each reception antenna ANTs is calculated by the signal processor **17** in sync with the transmission cycle Tr [sec] of the high-frequency transmission signal whenever the high-frequency transmission signal is transmitted.

In Modification 3 of the first embodiment, when variation in phase shift quantity in each reception antenna ANTs is initially set to be slow, a cycle of from the transmission start timing of the high-frequency transmission signal in the measurement period of the first reception antenna to the transmission end timing of the high-frequency transmission signal in the measurement period of the last reception antenna is set as a changeover cycle to switch whether the high-frequency transmission signal attenuated by the attenuator **4** is input to the signal combiner or not.

FIG. **5** is a block diagram illustrating the internal configuration of a radar device **1***c* according to Modification 3 of the first embodiment. FIG. **6** is a timing chart concerned with operation of the radar device **1***c* according to Modification 3 of the first embodiment. In FIG. **6**, (a) is an explanatory view illustrating a timing chart of a high-frequency transmission signal. In FIG. **6**, (b) is an explanatory view illustrating a timing chart of the high-frequency transmission signal input to a signal combiner **13**. In FIG. **6**, (c) is an explanatory view illustrating a period of measurement by each of reception antennas.

Although the difference in configuration and operation of Modification 3 of the first embodiment from the radar device **1** according to the first embodiment will be described with reference to FIGS. **5** and **6**, description of the same configuration and operation as those of the radar device **1** according to the first embodiment will be omitted.

In FIG. **5**, a radar receiver **3***c* has four reception antennas ANT**1** to ANT**4**, a switch **11**, a second switch **29**, a switch controller **12***c*, a signal combiner **13**, a RF receiver **14**, and a signal processor **17**.

The second switch **29** receives as an input the high-frequency transmission signal attenuated by the attenuator **4**. The second switch **29** uses a cycle of from the start timing of the measurement period of the first reception antenna ANT**1** to the end timing of the measurement period of the last reception antenna ANT**4** as a changeover cycle. The second switch **29** switches whether the input high-frequency transmission signal is input to the signal combiner **13** or not, in accordance with control of the switch controller **12***c* in each changeover cycle.

Specifically, as shown in (b) of FIG. **6**, the switch controller **12***c* uses a cycle of from time t_0 which is the start timing of the measurement period of the first reception antenna ANT**1** to time t_7 which is the end timing of the measurement period of the last reception antenna ANT**4** as a changeover cycle. The switch controller **12***c* controls the second switch **29** so that the attenuated high-frequency transmission signal input in sync with the transmission period of the high-frequency transmission signal is input to the signal combiner **13** in accordance with each changeover cycle.

The switch controller **12***c* controls the second switch **29** so that the attenuated high-frequency transmission signal input in sync with the transmission period of the high-frequency transmission signal is not input to the signal combiner **13** during a period of time t_8-t_{15} which is the next similar changeover cycle. Processing after that is the same as in the first embodiment.

Hence, in accordance with the radar device **1***c* according to Modification 3 of the first embodiment, accuracy of estimation of the arrival angle of the target and the distance to the target can be kept equal to that in the radar device **1** according to the first embodiment. Moreover, in accordance with the radar device **1***c*, there is a period in which inputting of the high-frequency transmission signal output from the attenuator **4** to the signal combiner **13** is blocked by the second switch **29**. In the period, the radar device **1***c* need not perform calculation of the phase shift quantity in each reception antenna ANTs and calculation of phase correction, etc. Accordingly, the radar device **1***c* can reduce power consumption caused by operation of the phase shift quantity and phase correction, etc. compared with the radar device **1** according to the first embodiment.

[Modification 4 of First Embodiment]

In the first embodiment, it is possible to correct the phase shift quantity in the reception signal due to operation of each element after the signal combiner **13** of the radar receiver **3**. When there is fixed phase error in each system from the reception antenna to the switch **11** which are respective elements before the signal combiner **13**, it is however difficult to correct the phase shift quantity inclusive of the fixed phase error.

In Modification 4 of the first embodiment, fixed phase error E(s) in each system from the reception antenna to the switch **11** is measured in advance so that the measured phase error E(s) is held in the signal processor.

The signal processor **17***d* has an A/D converter **18**, a reference transmission signal generator **19**, a correlation value calculator **20**, a timing controller **21**, a phase shift quantity calculator **22**, an intersystem fixed phase error storage **30**, a phase corrector **23**, a storage **24**, and an arrival angle and distance estimator **25**.

The intersystem fixed phase error storage **30** stores phase error E(s) measured in advance as fixed phase error E(s) in each system from the reception antenna ANTs to the switch **11** before the radar device **1***d* starts measurement for detecting the target. For example, the phase error E(s) is measured in accordance with each reception antenna ANTs and stored in a table format in accordance with the reception antenna ANTs.

For calculation of the phase shift quantity in each reception antenna ANTs, the phase shift quantity calculator **22** calculates the phase shift quantity $\Delta\theta(s)$ in accordance with the expression (6) including intersystem fixed phase error E(s) corresponding to the reception antenna ANTs stored in the intersystem fixed phase error storage **30** instead of the expression (2). Processing after that calculation is the same as in the first embodiment.

[Expression 6]

$$\Delta\theta(s)=\angle[AC(s,Nr)AC^*(s_0,Nr)]-E(s) \tag{6}$$

Hence, in accordance with the radar device **1***d* according to Modification 4 of the first embodiment, the phase shift quantity in each reception antenna ANTs inclusive of the intersystem fixed phase error in each system from the reception antenna ANTs to the switch **11** can be corrected more accurately. Hence, in accordance with the radar device **1***d*, deterioration of accuracy of measurement of the arrival angle of the target and the distance to the target can be suppressed.

[Second Embodiment]

In a second embodiment, a transmission antenna ANT**0** and reception antennas ANT**1** to ANT**4** are disposed so as to be located so that a high-frequency transmission signal transmitted from the transmission antenna ANT**0** can be directly received by each of the reception antennas ANT**1** to ANT**4** by using side lobes of the directional pattern of the transmission antenna ANT**0**, side lobes of the reception antennas ANT**1** to ANT**4** or the like. Moreover, in the second embodiment, the two measurement periods of a reference phase update period and an ordinary period are repeated at regular intervals so that calculation of the phase shift quantity in each reception antenna ANTs and correction of the phase component of the correlation value based on the calculated phase shift quantity are performed.

In the reference phase update period, the second switch **31** is turned on to perform inputting of the high-frequency transmission signal attenuated by the attenuator **4** to the signal combiner **13** in the same manner as in the first embodiment. Moreover, after inputting to the signal combiner **13**, the phase component of the correlation value in each reception antenna ANTs is corrected. Then, the second switch **31** is turned off to block inputting of the attenuated high-frequency transmission signal to the signal combiner **13**. In this state, a crosstalk signal directly received from the transmission antenna ANT**0** by the reception antenna ANTs is used so that the fixed phase error in each system of from the reception antenna ANTs to the switch **11** is calculated as a reference phase $\Delta\phi(s)$.

In the ordinary period, the second switch **31** is turned off to block inputting of the high-frequency transmission signal attenuated by the attenuator **4** to the signal combiner **13** after the reference phase $\Delta\phi(s)$ is calculated in the reference phase update period. In this state, the phase component of the correlation value in each reception antenna ANTs is corrected inclusive of the reference phase $\Delta\phi(s)$ calculated in the reference phase update period.

(Operation in Reference Phase Update Period in Radar Device **1***e* According to Second Embodiment)

The configuration of the radar device **1***e* according to the second embodiment and the operation in the reference phase update period will be described below.

The configuration and operation of the radar device **1***e* according to the second embodiment will be described with reference to FIGS. **8** and **9**. FIG. **8** is a block diagram illustrating the internal configuration of the radar device **1***e* according to the second embodiment. FIG. **9** is a timing chart concerned with operation in the reference phase update period of the radar device **1***e*.

In FIG. **9**, (a) is an explanatory view illustrating a timing chart of a high-frequency transmission signal. In FIG. **9**, (b) is an explanatory view illustrating a timing chart of the high-frequency transmission signal input to the signal combiner **13**. In FIG. **9**, (c) is an explanatory view illustrating a timing chart of a crosstalk signal in the case where the high-frequency transmission signal directly goes to the reception antenna ANTs. In FIG. **9**, (d) is an explanatory view illustrating a period of measurement by each reception antenna ANTs.

In FIG. **9**, (e) is an explanatory view illustrating an output of the reception signal from the switch **11** and a period of measurement by each reception antenna ANTs. In FIG. **9**, (f) is an explanatory view illustrating an output from the signal combiner **13**, a period of measurement by each reception antenna and a timing for calculating a phase shift quantity. In FIG. **9**, (g) is an explanatory view illustrating a period for storing a correlation value between a transmission signal and a reception signal.

As shown in FIG. **8**, the radar device **1***e* has an oscillator Lo, a radar transmitter **2**, a radar receiver **3***e*, a transmission antenna ANT**0**, reception antennas ANT**1** to ANT**4**, and an attenuator **4**. Because the configuration and operation (see (a) of FIG. **9**) of the radar transmitter **2** are the same as those in the first embodiment, description of the configuration and operation of the radar transmitter **2** will be omitted. Moreover, because the operation (see (b) of FIG. **9**) of the attenuator **4** is the same as in the first embodiment, description of the operation of the attenuator **4** will be omitted.

The radar receiver **3***e* has four reception antennas ANT**1** to ANT**4**, a switch **11**, a second switch **31**, a switch controller **12***e*, a signal combiner **13**, a RF receiver **14**, and a signal processor **17***e*.

The RF receiver **14** has a power amplifier **15**, and a frequency converter **16**. The signal processor **17***e* has an ND converter **18**, a reference transmission signal generator **19**, a correlation value calculator **20**, a timing controller **21**, a reference phase storage **32**, a phase shift quantity calculator **22**, a phase corrector **23**, a storage **24**, and an arrival angle and distance estimator **25**.

The reception antennas ANT**1** to ANT**4** form an array antenna of four reception antennas ANT**1** to ANT**4**. The reception antennas ANT**1** to ANT**4** receive both a signal obtained due to reflection of a high-frequency transmission signal transmitted from the radar transmitter **2** by a target and a feeble high-frequency transmission signal transmitted from the transmission antenna ANT**0** and directly going to each of the reception antennas ANT**1** to ANT**4** (see (c) of FIG. **9**).

The feeble high-frequency transmission signal directly going to the reception antennas ANT**1** to ANT**4** is based on side lobes of the directional pattern of the transmission antenna ANT**0**, side lobes of the reception antennas ANT**1** to ANT**4**, or the like.

Although description will be made on the assumption that the number of elements of the array antenna in the radar device **1***e* according to the second embodiment is 4 as shown in FIG. **8**, the number of elements of the array antenna is not limited to 4.

The switch **11** is provided with switching ports corresponding to the four reception antennas ANT**1** to ANT**4** so that the switch **11** is connected to the reception antennas. In the switch **11**, the respective switching ports corresponding to the four reception antennas ANT**1** to ANT**4** for receiving signals reflected by a target are changed sequentially under control of the switch controller **12***e* so that a single switching port is selected so that the switch **11** is connected to a reception antenna corresponding to the switching port. The switch **11** outputs a reception signal received by the selected reception antenna to the signal combiner **13**.

The second switch **31** switches whether the high-frequency transmission signal attenuated by the attenuator **4** is input to the signal combiner **13** or not, in accordance with control of the switch controller **12***e*.

The switch controller **12***e* controls the switch **11** so that the four reception antennas ANT**1** to ANT**4** are changed sequentially in a cycle of an integer multiple N (N: integer) of the transmission cycle Tr [sec] of the high-frequency transmission signal transmitted from the transmission antenna ANT**0**.

In the reference phase update period in the second embodiment, the switch controller **12***e* controls the switch **11** so that the four reception antennas ANT**1** to ANT**4** are changed sequentially in a cycle N (integer satisfying $N \geq 2$) not smaller than twice as much as the transmission cycle Tr [sec] of the high-frequency transmission signal. In FIG. **9**, (d) shows an example in which the switch **11** is controlled so that the four reception antennas ANT**1** to ANT**4** are changed sequentially

in a cycle (N=2) twice as much as the transmission cycle Tr [sec] of the high-frequency transmission signal.

The switch controller **12***e* controls the second switch **31** so that the high-frequency transmission signal attenuated by the attenuator **4** is input to the signal combiner **13** in the transmission period of the high-frequency transmission signal in a first half of the cycle (2Tr) twice as much as the transmission cycle Tr [sec] of the high-frequency transmission signal.

The switch controller **12***e* controls the second switch **31** so that the high-frequency transmission signal attenuated by the attenuator **4** is not input to the signal combiner **13** in the transmission period of the high-frequency transmission signal in a second half of the cycle (2Tr) twice as much as the transmission cycle Tr [sec] of the high-frequency transmission signal.

Specifically, as shown in (b) and (d) of FIG. **9**, the switch controller **12***e* changes the reception antenna for receiving a signal reflected by a target to the reception antenna ANT**1** in a period of time t_0-t_1. Moreover, the switch controller **12***e* controls the switch **11** so that the reception signal received by the reception antenna ANT**1** is output to the signal combiner **13** in a period of time t_1-t_2.

Moreover, the switch controller **12***e* controls the second switch **31** so that the high-frequency transmission signal attenuated by the attenuator **4** is input to the signal combiner **13** in a period of time t_0-t_1 which is the transmission period of the high-frequency transmission signal in a first half of the cycle twice as much as the transmission cycle Tr [sec] of the high-frequency transmission signal.

Accordingly, the period of time t_1-t_2 is used as a period of measurement by the reception antenna ANT**1** in the same manner as in the first embodiment. Moreover, the switch controller **12***e* controls the second switch **31** so that the high-frequency transmission signal attenuated by the attenuator **4** is not input to the signal combiner **13** in a period of time t_2-t_3 which is the transmission period of the high-frequency transmission signal in a second half of the cycle twice as much as the transmission cycle Tr [sec] of the high-frequency transmission signal.

In the period of time t_0-t_1 and the period of time t_2-t_3, a crosstalk signal of the high-frequency transmission signal transmitted from the transmission antenna ANT**0** because of side lobes of the directional pattern of the transmission antenna ANT**0**, side lobes of the reception antennas ANT**1** to ANT**4**, or the like, is received by the reception antenna ANT**1** in sync with the transmission period of the high-frequency transmission signal. The signal power of the crosstalk signal is considerably lower than the signal power of the attenuated high-frequency transmission signal.

Accordingly, with respect to the reception antenna ANT**1**, a correlation value having a phase shift quantity corrected based on the correlation value between the reference transmission signal and the reception signal in the reception antenna ANT**1** is calculated in a period of time t_0-t_2 in the same manner as in the first embodiment. Moreover, with respect to the reception antenna ANT**1**, intersystem fixed phase error caused by direct reception of the crosstalk signal in the reception antenna ANT**1** is calculated as a reference phase $\Delta\phi(1)$ in a period of time t_2-t_4.

The switch controller **12***e* controls the switch **11** so that the reception antenna is changed to the reception antenna ANT**2** in a period of time t_4-t_5 and the reception signal received by the reception antenna ANT**2** is output to the signal combiner **13** in a period of time t_5-t_6.

Moreover, the switch controller **12***e* controls the second switch **31** so that the high-frequency transmission signal attenuated by the attenuator **4** is input to the signal combiner **13** in a period of time t_4-t_5 which is the transmission period of the high-frequency transmission signal in a first half of the cycle twice as much as the transmission cycle Tr [sec] of the high-frequency transmission signal. Accordingly, the period of time t_5-t_6 is used as a period of measurement by the reception antenna ANT**2** in the same manner as in the first embodiment.

Moreover, the switch controller **12***e* controls the second switch **31** so that the high-frequency transmission signal attenuated by the attenuator **4** is not input to the signal combiner **13** in a period of time t_6-t_7 which is the transmission period of the high-frequency transmission signal in a second half of the cycle twice as much as the transmission cycle Tr [sec] of the high-frequency transmission signal.

In a period of time t_4-t_5 and a period of time t_6-t_7, a crosstalk signal due to direct reception of the high-frequency signal transmitted from the transmission antenna ANT**0** because of side lobes of the directional pattern of the transmission antenna ANT**0**, side lobes of the reception antennas ANT**1** to ANT**4**, or the like, is received by the reception antenna ANT**2** in sync with the transmission period of the high-frequency transmission signal. The signal power of the crosstalk signal is considerably lower than the signal power of the attenuated high-frequency transmission signal.

Accordingly, with respect to the reception antenna ANT**2**, a correlation value having a phase shift quantity corrected based on the correlation value between the reference transmission signal and the reception signal in the reception antenna ANT**2** is calculated in a period of time t_4-t_8 in the same manner as in the first embodiment. Moreover, with respect to the reception antenna ANT**2**, intersystem fixed phase error caused by reception of the crosstalk signal in the reception antenna ANT**2** is calculated as a reference phase $\Delta\phi(2)$ in a period of time t_6-t_8. The same thing applies to the other reception antennas ANT**3** and ANT**4**.

Incidentally, the reception signal output from the switch **11** shows a signal combined from a noise signal around the radar device **1** and the crosstalk signal in periods of times t_0-t_1, t_2-t_3, t_4-t_5, t_6-t_7 and t_8-t_9 as shown in (e) of FIG. **9**. Incidentally, because the signal power of the noise signal is very feeble compared with the signal power of the crosstalk signal, the reception signal output from the switch **11** can approximate the crosstalk signal.

The reception signal output from the switch **11** shows a signal combined from the crosstalk signal and a reception signal (not shown) corresponding to each measurement period (each of periods of times t_1-t_2, t_3-t_4, t_5-t_6 and t_7-t_8) in periods of times t_1-t_2, t_3-t_4, t_5-t_6 and t_7-t_8.

The signal combiner **13** combines a signal from a signal in which inputting of the high-frequency transmission signal output from the attenuator **4** is turned on or off by the second switch **31**, and the reception signal output from the switch **11**, and outputs the combined signal to the power amplifier **15** of the RF receiver **14**.

When the second switch **31** is on, the signal combiner **13** combines a signal from the output of the attenuator **4** and the output of the switch **11**. In this case, the output of the switch **11** includes a crosstalk signal which goes through side lobes of the transmission or reception antenna. When the average power of the crosstalk signal is Z [dB], the signal power output from the signal combiner is (Y+Z) [dB].

The average power Z [dB] of the crosstalk signal which goes through side lobes of the transmission or reception antenna is set to be signal power allowed to be received by the RF receiver **14** when an antenna pattern including the side lobe level of the transmission/reception antenna is designed. Incidentally, the signal power Y of the attenuator output of the

radar transmission signal is attenuated to a sufficiently higher level (3 dB to 10 dB) than the reception signal level Z in this interval and then mixed by the signal combiner of the radar receiver.

However, when autocorrelation characteristic of the radar transmission signal has side lobes, the signal power Y of the attenuator output of the radar transmission signal is set to be low so that the side lobe level is a level undisturbed by the radar measurement period. The timing of mixing the attenuator output of the radar transmission signal is synchronized with the radar transmission signal while the time lag is suppressed.

Because operation of the RF receiver **14** is the same as in the first embodiment, description of the operation of the RF receiver **14** will be omitted.

Because operation of the A/D converter **18** is the same as in the first embodiment, description of the operation of the ND converter **18** will be omitted.

Because operation of the reference transmission signal generator **19** is the same as in the first embodiment, description of the operation of the reference transmission signal generator **19** will be omitted.

The correlation value calculator **20** calculates a correlation value AC(s,k) between the complex signal x(s,k) of the reception signal received by the reception antenna ANTs and the reference transmission signal r(n) output from the reference transmission signal generator **19**. Assume now that a sliding correlation value as shown in the expression (1) is calculated as the correlation value.

Incidentally, when the transmission signal generated by the transmission signal generator **5** is a baseband signal r(n) composed of real numbers, this signal r(n) is used as the reference transmission signal for calculation of the sliding correlation value AC(s,k). On the other hand, when the transmission signal generated by the transmission signal generator **5** is a baseband signal r(n) composed of an in-phase signal and a quadrature signal, a complex conjugate value of this signal r(n) is used.

The timing controller **21** notifies the phase shift quantity calculator **22** of the timing information of termination of calculation of the sliding correlation value based on the timing k_0 of termination of the period Tw [sec] of presence of the high-frequency transmission signal transmitted from the transmission antenna ANT**0** and input to the signal combiner **13** through the attenuator **4** while the timing k_0 is regarded as the timing of termination of calculation of the sliding correlation value $AC(s,k_0)$ by the correlation value calculator **20**.

As shown in (f) of FIG. **9**, the timing k_0 of termination of the period Tw [sec] of presence of the high-frequency transmission signal transmitted from the transmission antenna ANT**0** and input to the signal combiner **13** through the attenuator **4** is times t_1, t_5 and t_9 and corresponds to discrete time k=Nr.

The timing controller **21** notifies the phase corrector **23** of the timing information indicating that the sliding correlation value AC(s,k) corrected by the phase corrector **23** is stored in the storage **24**, with respect to the sliding correlation value AC(s,k) between the complex signal x(s,k) of the reception signal received by the reception antenna ANTs and the reference transmission signal r(n) output from the reference transmission signal generator **19**. Incidentally, discrete time k is from 2Nr to (Nr+Nu) and from (Nr+Nu)+2Nr to 2(Nr+Nu) (see (f) of FIG. **9**).

The phase shift quantity calculator **22** extracts the sliding correlation value AC(s,Nr) in the reception antenna ANTs and the sliding correlation value $AC(s_0,Nr)$ in a reference reception antenna $ANTs_0$ (which will be described later) based on the timing information (e.g. time t_1, t_5, t_9) which is given from the timing controller **21** and which indicates that the period Tw [sec] of presence of the high-frequency transmission signal transmitted from the transmission antenna ANT**0** and input to the signal combiner **13** through the attenuator **4** is terminated.

Here, the reception antenna $ANTs_0$ which is one of the four reception antennas ANT**1** to ANT**4** shown in FIG. **8** and which is used as a reference for calculating the phase shift quantity is referred to as reference reception antenna. Moreover, the sliding correlation value $AC(s_0,Nr)$ in the reference reception antenna $ANTs_0$ and the sliding correlation value AC(s,Nr) in the reception antenna ANTs have been already calculated by the correlation value calculator **20**.

The phase shift quantity calculator **22** calculates the phase shift quantity $\Delta\theta(s)$ in the reception antenna ANTs in accordance with the expression (2) based on the sliding correlation value AC(s,Nr) in the reception antenna ANTs and the sliding correlation value $AC(s_0,Nr)$ in the reference reception antenna $ANTs_0$. The phase shift quantity calculator **22** outputs the calculated phase shift quantity $\Delta\theta(s)$ to the phase corrector **23**.

Moreover, the phase shift quantity calculator **22** extracts the correlation value AC(s,Nr+Nu+Nr+dt) in the crosstalk signal calculated by the correlation value calculator **20** based on the timing information (e.g. time t_3, t_7) which is given from the timing controller **21** and which indicates that calculation of the sliding correlation value is terminated. The phase shift quantity calculator **22** corrects the phase shift quantity $\Delta\theta(s)$ in accordance with the expression (7) based on the extracted correlation value AC(s,Nr+Nu+Nr+dt). Moreover, the phase shift quantity calculator **22** calculates intersystem fixed phase error in each system including the reception antenna ANTs (reception antenna ANT**1** at time t_3) and the switch **11** as a reference phase $\Delta\phi(s)$ in the reception antenna ANTs.

Assume now that the sliding correlation value AC(s,Nr+Nu+Nr+dt) in the reception antenna ANTs has been already calculated by the correlation value calculator **20**.

[Expression 7]

$$\Delta\Phi(s)=\angle[AC(s,Nr+Nu+Nr+dt)]-\Delta\theta(s) \tag{7}$$

Here, as described above, discrete time k=Nr+Nu+Mr+dt shows timing when the crosstalk signal is received by the reception antenna ANTs. Here, dt [sec] shows a delay of arrival time of the signal directly received from side lobes of the transmission antenna ANT**0** through side lobes of the reception antenna. dt depends on arrangement of the transmission antenna ANT**0** and the reception antennas ANT**1** to ANT**4** (distance between the transmission antenna and each reception antenna). It is however preferable that dt is not smaller than one pulse width in the pulse train.

In this case, when the sliding correlation value AC(s,Nr) in the reception antenna ANTs is calculated based on the timing information indicating that the period Tw [sec] of presence of the high-frequency transmission signal transmitted from the transmission antenna ANT**0** and input to the signal combiner **13** through the attenuator **4** is terminated, a correlation value can be obtained so that the influence of the crosstalk signal superposedly received is reduced. Accordingly, the reference phase can be calculated more accurately.

The phase corrector **23** corrects the sliding correlation value AC(s,k) calculated by the correlation value calculator **20** in accordance with the expression (4) based on the phase shift quantity output from the phase shift quantity calculator **22**. The phase corrector **23** stores the phase component of the corrected sliding correlation value AC(s,k) in the storage **24**.

The phase corrector **23** stores the sliding correlation value (see the expression (5)) having the corrected phase component in the reception antenna ANTs at discrete time k=2Nr to (Nr+Nu) and (Nr+Nu+Nr) to 2(Nr+Nu) in the storage **24** based on the timing information output from the timing controller **21** for indicating that the corrected sliding correlation value is stored.

Because operation of the arrival angle and distance estimator **25** is the same as in the first embodiment, description of operation of the arrival angle and distance estimator **25** will be omitted.

(Operation in Ordinary Period in Radar Device **1***e* According to Second Embodiment)

Although the difference of operation in the ordinary period of the radar device **1***e* according to the second embodiment from the operation in the reference phase update period will be described below, description of the same in contents as the operation in the reference phase update period will be omitted.

The switch controller **12***e* controls the switch **11** so that the four reception antennas ANT**1** to ANT**4** are sequentially changed in a cycle of an integer multiple N (N: integer) of the transmission cycle Tr [sec] of the high-frequency transmission signal transmitted from the transmission antenna ANT**0**. In the ordinary period in the second embodiment, the switch controller **12***e* controls the switch **11** so that the four reception antennas ANT**1** to ANT**4** are sequentially changed in a cycle (N=2) twice as much as the transmission cycle Tr [sec] of the high-frequency transmission signal, similarly to (d) of FIG. **9**.

In the ordinary period, the switch controller **12***e* controls the second switch **31** so that inputting of the high-frequency transmission signal attenuated by the attenuator **4** to the signal combiner **13** is blocked.

The correlation value calculator **20** calculates the sliding correlation value AC(s,Nr+dt) between the crosstalk signal in the reception antenna ANTs and the reference transmission signal in the same manner as the correlation value calculator **20** in the first embodiment.

The phase shift quantity calculator **22** extracts the correlation value AC(s,Nr+dt) between the crosstalk signal in the reception antenna ANTs and the reference transmission signal based on the timing of termination of calculation of the sliding correlation value output from the timing controller **21**, and corrects the phase shift quantity of the reception antenna ANTs in accordance with the expression (8) based on the reference phase Δϕ(s) stored in the reference phase storage **32**.

[Expression 8]

$$\Delta\theta(s)=\angle[AC(s,Nr+dt)]-\Delta\Phi(s) \quad (8)$$

The phase corrector **23** corrects the sliding correlation value AC(s,k) calculated by the correlation value calculator **20** in accordance with the expression (4) based on the phase shift quantity output from the phase shift quantity calculator **22**. The phase corrector **23** stores the phase component of the corrected sliding correlation value AC(s,k) in the storage **24**.

The phase corrector **23** stores the sliding correlation value (see the expression (5)) having the corrected phase component in the reception antenna ANTs at discrete time k=2Nr to (Nr+Nu) in the storage **24** based on the timing information output from the timing controller **21** for indicating that the corrected sliding correlation value is stored.

As described above, in accordance with the radar device **1***e* according to the second embodiment, like the radar device **1** according to the first embodiment, the phase shift quantity in the reception antenna can be calculated properly based on the correlation value between the reception signal reflected by the target and received by the reception antenna ANTs and the reference transmission signal.

Moreover, in accordance with the radar device **1***e*, intersystem fixed phase error in the reception antenna ANTs can be calculated properly based on the correlation value between the crosstalk signal directly going from the transmission antenna ANT**0** to the reception antenna ANTs and the reference transmission signal.

Hence, in accordance with the radar device **1***e*, intersystem fixed phase error in each system of the reception antenna ANTs and the switch **11** and the phase shift quantity based on the correlation value between the reference transmission signal and the reception signal can be calculated properly while the influence on measurement performance of the radar device is suppressed.

Moreover, in accordance with the radar device **1***e*, the phase error can be corrected in real time even when the intersystem phase error in each system of the reception antenna ANTs and the switch **11** varies with time in a portion preceding the signal combiner **13**.

The radar device **1***e* can suppress deterioration of accuracy of measurement of the arrival angle of the target ad the distance to the target by properly correcting the phase component of the correlation value in each reception antenna ANTs based on the properly calculated phase error and phase shift.

Moreover, in accordance with the radar device **1***e*, like the radar device **1** according to the first embodiment, it is unnecessary to provide any switching port for calibration in the switch **11** compared with the conventional radar device. Accordingly, the radar device **1***e* can perform calibration for the reception antenna ANTs in accordance with transmission of the high-frequency transmission signal, so that accurate measurement can be performed compared with the conventional radar device.

[Third Embodiment]

The configuration and operation of a radar device **1***f* according to a third embodiment will be described with reference to FIGS. **11** and **12**. FIG. **11** is a block diagram illustrating the internal configuration of the radar device **1***f* according to the third embodiment.

FIG. **12** is a timing chart concerned with operation of the radar device **1***f* according to the third embodiment. In FIG. **12**, (a) is an explanatory view illustrating a timing chart of a high-frequency transmission signal. In FIG. **12**, (b) is an explanatory view illustrating a timing chart of the high-frequency transmission signal input to a signal combiner **13***f* from an attenuator **4**. In FIG. **12**, (c) is an explanatory view illustrating a period of measurement by each of reception antennas ANT**1** to ANT**4**. In FIG. **9**, (d) is an explanatory view illustrating a reception signal output from the signal combiner **13***f* and a period of measurement by each of the reception antennas ANT**1** to ANT**4**.

In FIG. **12**, (e) is an explanatory view illustrating an output of the signal combiner **13***f*, a period of measurement by each of the reception antennas ANT**1** to ANT**4** and a timing of calculating a phase shift quantity. In FIG. **12**, (f) is an explanatory view illustrating a period for storing a correlation value between a transmission signal and a reception signal.

As shown in FIG. **11**, the radar device **1***f* has an oscillator Lo, a radar transmitter **2**, a radar receiver **3***f*, a transmission antenna ANT**0**, reception antennas ANT**1** to ANT**4**, and an attenuator **4**. Because the configuration of the radar device **1***f* is the same as in the first embodiment except the radar receiver **3***f*, description thereof will be omitted. With respect

to the configuration of the radar receiver **3***f* in the radar device **1***f*, mainly different points in configuration and operation will be described below.

As shown in (a) of FIG. **12**, assume that Nr [pieces] of discrete time samples are provided as a baseband transmission signal r(n) in a period Tw [sec] of presence of a high-frequency transmission signal transmitted from the transmission antenna ANT**0** from the radar transmitter **2** whereas Nu [pieces] of discrete time samples are provided as a baseband transmission signal r(n) in a period (Tr-Tw) [sec] of absence of the high-frequency transmission signal.

The parameter Tr is a transmission cycle [sec] of the high-frequency transmission signal transmitted from the transmission antenna ANT**0**. As shown in (a) of FIG. **12**, the high-frequency transmission signal is transmitted cyclically by the transmission cycle Tr in periods of times t_0-t_1, t_2-t_3, t_4-t_5, t_6-t_7 and t_8-t_9 but not transmitted in periods of times t_1-t_2, t_3-t_4, t_5-t_6 and t_7-t_8. After time t_9, transmission of the high-frequency transmission signal is repeated in the same manner.

As shown in (b) of FIG. **12**, the attenuator **4** attenuates the signal power of the high-frequency transmission signal output from the directional coupler **10** to predetermined signal power Y [dB] in sync with the transmission period of the high-frequency transmission signal.

The radar receiver **3***f* has four reception antennas ANT**1** to ANT**4**, a transmission signal changer **40**, a switch controller **12***f*, signal combiners **13***f***1** to **13***f***4**, RF receivers **14***f***1** to **14***f***4**, a phase controller **41**, phase shifters **42-1** to **42-4**, a signal adder **33**, and a signal processor **17**. The RF receiver **14***f* has a power amplifier **15** and a frequency converter **16**. The signal processor **17** has an A/D converter **18**, a reference transmission signal generator **19**, a correlation value calculator **20**, a timing controller **21**, a phase shift quantity calculator **22**, a phase corrector **23**, a storage **24**, and an arrival angle and distance estimator **25**.

The reception antennas ANT**1** to ANT**4** form an array antenna of four reception antennas ANT**1** to ANT**4**. The reception antennas ANT**1** to ANT**4** receive both a signal obtained due to reflection of the high-frequency transmission signal transmitted from the radar transmitter **2** by a target and a noise signal around the radar device **1** as a reception signal. Although description will be made in the case where the number of elements of the array antenna in the radar device **1***f* according to the third embodiment is 4 as shown in FIG. **11**, the number of elements of the array antenna is not limited to 4.

In the transmission signal changer **40**, respective switching ports corresponding to the four signal combiners **13***f***1** to **13***f***4** are changed sequentially under control of the switch controller **12***f*. By this changing, a single switching port is selected so that a signal combiner **13***fq* corresponding to the switching port is connected to the transmission signal changer **40**. Here, the parameter q is a natural number up to the number of reception antennas. In the case of FIG. **11**, q is 1 to 4. The transmission signal changer **40** outputs the high-frequency transmission signal from the attenuator **4** to the selected signal combiner **13***fq*.

The switch controller **12***f* sequentially changes the respective switching ports of the transmission signal changer **40** corresponding to the four signal combiners **13***f***1** to **13***f***4** in a cycle of an integer multiple N (N: integer) of the transmission cycle Tr [sec] of the high-frequency transmission signal. Although the third embodiment shows an example in which the switch controller **12***f* controls the transmission signal changer **40** to sequentially change the respective switching ports of the transmission signal changer **40** corresponding to the four signal combiners **13***f***1** to **13***f***4** in the same cycle (N=1) as the transmission cycle Tr [sec] of the high-frequency transmission signal, the third embodiment is not limited thereto.

Specifically, the switch controller **12***f* performs switching so that the output of the transmission signal changer **40** which is the high-frequency transmission signal from the attenuator **4** is input to the selected signal combiner **13***f***1** in a period of time t_0-t_1. Here, changeover transition time ΔTsw in the transmission signal changer **40** may be considered so that the changeover operation is performed prior to time t_0-ΔTsw.

The switch controller **12***f* performs switching so that the output of the transmission signal changer **40** which is the high-frequency transmission signal from the attenuator **4** is input to the selected signal combiner **13***f***2** in a period of time t_2-t_3.

The switch controller **12***f* performs switching so that the output of the transmission signal changer **40** which is the high-frequency transmission signal from the attenuator **4** is input to the selected signal combiner **13***f***3** in a period of time t_4-t_5.

The switch controller **12***f* performs switching so that the output of the transmission signal changer **40** which is the high-frequency transmission signal from the attenuator **4** is input to the selected signal combiner **13***f***4** in a period of time t_6-t_7.

After that, the switch controller **12***f* performs switching in the same manner so that the signal is input to the signal combiner **13***fq* in a cycle of an integer multiple N (N: integer) of the transmission cycle Tr [sec] of the high-frequency transmission signal. When the high-frequency transmission signal output from the attenuator **4** is not included as a result of interposition of the transmission signal changer **40**, the signal combiner **13***fq* has only the reception signal output from the reception ANTq as shown in (c) of FIG. **12**.

On the other hand, when the high-frequency transmission signal output from the attenuator **4** is included as a result of interposition of the transmission signal changer **40**, the signal combiner **13***fq* combiners a signal from the reception signal output from the reception ANTq and the high-frequency transmission signal output from the attenuator **4** and outputs the combined signal to the RF receiver **14***fq*, as shown in (d) of FIG. **12**. Here, when the average signal power of the reception signal output from the reception ANTq is Z [dB], the signal power of the combined signal output from the signal combiner **13***fq* is (Y+Z) [dB].

Incidentally, when the signal power Y [dB] of the high-frequency transmission signal output from the attenuator **4** is included in the signal combiner **13***fq* as a result of interposition of the transmission signal changer **40**, it is preferable that the signal power is attenuated to sufficiently higher signal power (e.g. 3 [dB] to 10 [dB]) than the signal power received by the reception antenna ANTs in the transmission period (of e.g. time t_0-t_1 etc.) of the high-frequency transmission signal. For this reason, when power of the high-frequency transmission signal output from the attenuator **4** is insufficient, a level adjuster for adjusting the level to a predetermined level is disposed in place of the attenuator **4** so that amplification through an amplification circuit included in the level adjuster makes up for shortage of power. The level adjuster may be formed from the attenuator **4**.

When there are side lobes in autocorrelation characteristic of the high-frequency transmission signal, it is preferable that the attenuator **4** attenuates the signal power of the high-frequency transmission signal output from the directional coupler **10** to such signal power that the side lobe level has no influence on the measurement period of the radar device **1**.

Each of the RF receivers **14***f***1** to **14***f***4** generates a timing clock based on a reference signal generated by the oscillator Lo so that the reference signal is multiplied by a predetermined number. Each of the RF receiver **141***f* to **14***f***4** operates based on the generated timing clock. Each of the RF receivers **14***f***1** to **14***f***4** receives as an input the combined signal combined by corresponding one of the signal combiners **13***f***1** to **13***f***4**, amplifies the signal power of the input combined signal to predetermined signal power and frequency-converts the signal to a baseband signal.

Moreover, each of the RF receivers **14***f***1** to **14***f***4** shifts the phase component of part of the combined signal by 90 [degrees] based on quadrature detection to thereby generate a baseband reception signal composed of an in-phase signal and a quadrature signal, and outputs the generated reception signal to the phase shifter (PS: Phase Shifter) **32**. The baseband reception signal composed of an in-phase signal I(t) and a quadrature signal Q(t) which is the output of the RF receiver **14***fq* at time t is described here as a complex signal xq(t)=Iq(t)+Qq(t).

The phase shifters **42-1** to **42-4** receive output signals of the RF receivers **14***f***1** to **14***f***4** as inputs respectively, and give phase rotations ϕ**1** to ϕ**4** designated by the phase controller **41** to the input output signals of the RF receivers **14***f***1** to **14***f***4** respectively.

The signal adder **33** applies an adding process to the respective outputs of the phase shifters **42-1** to **42-4**. Here, an output signal OS(t) of the signal adder **33** at time t can be represented by the expression (9). Incidentally, j is an imaginary unit.

[Expression 9]

$$OS(t) = \sum_{q=1}^{4} x_q(t)\exp(j\phi_q) \tag{9}$$

By operation of the phase shifters **42-1** to **42-4** and the signal adder **33**, the radar receiver **3***f* can form directivity of the reception antenna array in a predetermined direction. For example, when reception antennas are disposed on a line at regular intervals of Dant, a reception beam (directivity of the reception antenna array) can be formed in a direction θ as represented by $\phi q=(q-1)Dant\cdot\sin\theta\cdot 2\pi/\lambda$.

The phase controller **41** can change the phase rotations ϕ**1** to ϕ**4** cyclically based on a control signal in a cycle of an integer multiple N2 (N2: integer) of the transmission cycle Tr [sec] of the high-frequency transmission signal in the switch controller **12***f*. Accordingly, the reception beam can be changed in accordance with the cycle of an integer multiple N2 (N2: integer) of the transmission cycle Tr [sec].

The A/D converter **18** performs sampling at discrete time k for the output of the signal adder **33** to thereby convert the reception signal into digital data. The reception signal at discrete time k which is the output of the signal adder **33** in the case where the high-frequency transmission signal output from the attenuator **4** is included in the signal combiner **13***fq* through the transmission signal changer **40** is described here as a complex signal of a complex number x(q,k)=I(q,k)+jQ(q,k) using an in-phase signal component I(q,k) and a quadrature signal component Q(q,k) in the output of the signal adder **33**. Incidentally, j is an imaginary unit.

Moreover, the parameter k shows discrete time corresponding to the number of samples of the baseband transmission signal r(n) included in the high-frequency transmission signal. In the third embodiment, the timing of transmitting the transmission signal is set at k=1 and k=1 to (Nr+Nu). Accordingly, as shown in (e) of FIG. **12**, the parameter k satisfies k=1 in the timing of time t_0, time t_2, time t_4, time t_6 and time t_s. Moreover, the parameter k satisfies k=Nr in the timing of time t_1, time t_3, time t_5, time t_7 and time t_9.

The reference transmission signal generator **19** generates a timing clock based on a reference signal generated by the oscillator Lo in the same manner as the transmission signal generator **5** in sync with operation of the transmission signal generator **5** so that the reference signal is multiplied by a predetermined number. The reference transmission signal generator **19** cyclically generates a reference transmission signal r(n) of the same baseband as the transmission signal generated by the transmission signal generator **5** based on the generated reference signal. The reference transmission signal generator **19** outputs the generated reference transmission signal r(n) to the correlation value calculator **20**.

The correlation value calculator **20** calculates a correlation value AC(q,k) between the complex signal x(q,k) which is the reception signal output at discrete time k from the signal adder **33**, and the reference transmission signal r(n) output from the reference transmission signal generator **19**. Assume now that a sliding correlation value as shown in the expression (1) is calculated as the correlation value.

The sliding correlation value AC(q,k) is a correlation value at discrete time k between the reception signal output at discrete time k from the signal adder **33**, that is, the reception signal (including a reflected signal and a noise signal) received by a reception beam having a predetermined direction, and the reference transmission signal. The asterisk (*) in the expression (1) shows a complex conjugate operator. The sliding correlation value AC(q,k) is calculated in periods of k=1 to (Nr+Nu). That is, the sliding correlation value AC(q,k) is calculated in periods of times t_0-t_2, t_2-t_4, t_4-t_6, t_6-t_8, etc.

Incidentally, when the transmission signal generated by the transmission signal generator **5** is a baseband signal r(n) composed of real numbers, the signal r(n) is used as the reference transmission signal in calculation of the sliding correlation value AC(q,k). On the other hand, when the transmission signal generated by the transmission signal generator **5** is a baseband signal r(n) composed of an in-phase signal and a quadrature signal, a complex conjugate value of the signal r(n) is used.

The timing controller **21** regards the timing k_0 of completion of the period Tw [sec] (transmission period) of presence of the high-frequency transmission signal transmitted from the transmission antenna ANT**0** as the timing of completion of calculation of the sliding correlation value AC(q,k_0) by the correlation value calculator **20**, and notifies the phase shift quantity calculator **22** of the timing information of completion of calculation of the sliding correlation value AC(q,k_0).

The timing controller **21** notifies the phase shift quantity calculator **22** and the phase corrector **23** of the timing of sequentially changing the respective switching ports of the transmission signal changer **40** corresponding to the four signal combiners **13***f***1** to **13***f***4** and the information of the selected signal combiner **13***f* in a cycle of an integer multiple N (N: integer) of the transmission cycle Tr [sec] of the high-frequency transmission signal. The timing controller **21** notifies the phase shift quantity calculator **22** of the timing of permitting cyclical change the phase rotations ϕ**1** to ϕ**4** and the quantities of the phase rotations in the phase controller **32** based on a control signal in a cycle of an integer multiple N2 (N2: integer) of the transmission cycle Tr [sec] of the high-frequency transmission signal.

As shown in (c) and (e) of FIG. **12**, the timing k_0 of completion of the period Tw [sec] of presence of the high-frequency

transmission signal transmitted from the transmission antenna ANT**0** and the timing of completion of calculation of the sliding correlation value AC(q,k_0) by the correlation value calculator **20** are the same points of time t_1, t_3, t_5, t_7 and t_9 and correspond to discrete time k_0=Nr.

The timing controller **21** notifies the phase corrector **23** of the timing information for indicating that the sliding correlation value AC(q,k) corrected by the phase corrector **23** is stored in the storage **24** with respect to the sliding correlation value AC(q,k) between the complex signal x(q,k) of the reception signal output at discrete time k from the signal adder **33**, that is, the reception signal received by a reception beam having a predetermined direction, and the reference transmission signal r(n) output from the reference transmission signal generator **19**. However, discrete time k satisfies k=2Nr to (Nr+Nu) (see (f) of FIG. **12**).

Incidentally, the discrete time k can be also set in a range of k=(Nr+1) to (Nr+Nu). However, the start timing of discrete time k at which the sliding correlation value AC(q,k) is stored in the storage **24** is determined in the timing controller **21** not at k=Nr but at k=2Nr on the assumption that not a target nearest to the radar device **1***f* but a target at a predetermined distance [m] or farther from the radar device **1***f* is detected.

Accordingly, because it is not necessary to consider that the intensive reception level is received from a target nearest to the radar device **1** without distortion, the dynamic range in the radar receiver **3** of the radar device **1** can be reduced. With respect to the start timing of discrete time k at which the sliding correlation value AC(q,k) is stored in the storage **24**, in the timing controller **21**, the same thing applies to the flowing embodiments.

Or, the discrete time k can be set in a range of k=(Nr+1) to (Nu). Accordingly, the time range of superposing the high-frequency transmission signal on the sliding correlation value AC(q,k) can be eliminated so that deterioration of radar measurement performance can be prevented when the transmission signal directly goes to the radar receiver.

The phase shift quantity calculator **22** extracts a sliding correlation value AC(q,Nr) included in the high-frequency transmission signal output from the attenuator **4** to the signal combiner **13***fq* through the transmission signal changer **40** and a sliding correlation value AC(q**0**,Nr) in the reference reception antenna ANTs**0** (which will be described later) based on the timing information given from the timing controller **21** for indicating the completion of calculation of the sliding correlation value.

Here, a reception antenna q_0 which is one of the four reception antennas ANT**1** to ANT**4** shown in FIG. **11** and which includes a signal combiner **13***f*q_0 as a reference for calculating a phase shift quantity is referred to as reference reception antenna. Assume further that the sliding correlation value AC(q_0,Nr) in the reference reception antenna ANTq_0 and the sliding correlation value AC(q,Nr) in the reception antenna ANTq have been already calculated by the correlation value calculator **20**.

The phase shift quantity calculator **22** calculates a phase shift quantity Δθ(q) in the reception antenna ANTq in accordance with the expression (10) based on the sliding correlation value AC(q,Nr) in the reception antenna ANTq and the sliding correlation value AC(q_0,Nr) in the reference reception antenna ANTq_0. The phase shift quantity calculator **22** outputs the calculated phase shift quantity Δθ(q) to the phase corrector **23**.

[Expression 10]

$$\Delta\theta(q)=\angle[AC(q,Nr)AC^*(q_0,Nr)] \tag{10}$$

In the expression (10), each of the parameter q and the parameter q_0 shows a natural number not larger than the number of reception antennas. Each of the parameters s and s_0 shows any one of 1, 2, 3 and 4. The asterisk (*) shows a complex conjugate operator.

The phase corrector **23** corrects the phase component of the sliding correlation value AC(q,k) in the reception antenna ANTq calculated by the correlation value calculator **20** in accordance with the expression (11) based on the phase shift quantity output from the phase shift quantity calculator **22**.

[Expression 11]

$$\angle[AC(q,k)]-\angle\theta(q)-\phi_q \tag{11}$$

The phase corrector **23** stores the sliding correlation value (see the expression (12)) having the corrected phase component in the reception antenna ANTq at discrete time of k=2Nr to (Nr+Nu) in the storage **24** based on the timing information output from the timing controller **21** for indicating that the corrected sliding correlation value is stored.

[Expression 12]

$$|AC(q,k)|\exp(j\{\angle[AC(q,k)]-\Delta\theta(q)-\phi_q\}) \tag{12}$$

The arrival angle and distance estimator **25** performs calculation to estimate the arrival angle of the target and the distance to the target based on the sliding correlation value AC(q,k) having the corrected phase component in each reception antenna ANTq stored in the storage **24**. The calculation to estimate the arrival angle by the arrival angle and distance estimator **25** is a technique which has become publicly known. For example, this technique can be achieved by referring to Non-Patent Literature 2 which has been described above. Moreover, the calculation to estimate the distance to the target by the arrival angle and distance estimator **25** can be achieved by referring to Reference Non-Patent Literature 1 which has described above.

For example, the arrival angle and distance estimator **25** calculates reception signal power in the reception antenna based on the correlation value having the corrected phase component in the reception antenna ANTq with respect to the arrival angle of the target. The reception signal power includes the phase component at the arrival angle of the target. The arrival angle and distance estimator **25** estimates the angle of the phase component in the case where the reception signal power takes a maximum value, as the arrival angle of the target.

For example, the arrival angle and distance estimator **25** estimates the distance to the target based on the time difference between the discrete time in the case where the correlation value takes a maximum value and the transmission time of the high-frequency transmission signal based on the correlation value having the corrected phase component in the reception antenna ANTq with respect to the distance to the target.

As described above, in accordance with the radar device **1***f* according to the third embodiment, a phase shift quantity of a phase component in a correlation value between a reception signal received by each of reception antennas and a transmission signal can be calculated properly as measurement performance of the radar device while, for example, influence on the measurement time or measurement distance range is suppressed.

Moreover, the radar device **1***f* can correct the phase component of the correlation value in each reception antenna ANTq based on the properly calculated phase shift quantity to

thereby suppress deterioration of accuracy of measurement of the arrival angle of the target and the distance to the target.

Moreover, in accordance with the radar device **1***f*, because the transmission signal for calibration is the same as the transmission signal for measurement, execution can be made without addition of any correlation calculator for calibration to the signal processor **17**, so that execution can be made without complication of circuit configuration.

Although the phase shifter **42**-*q* in the third embodiment gives phase rotation to the baseband signal which is the output of the RF receiver **14***fq*, the third embodiment is not limited thereto. The same effect can be obtained even in a configuration that phase rotation is given to a high-frequency signal or an intermediate-frequency signal obtained in the RF receiver **14***fq*. Or the same effect can be obtained even in a configuration that phase rotation is given to a signal of the oscillator Lo input to the RF receiver **14***fq*.

Although the phase shifter **42** in the third embodiment analogically gives phase rotation to the baseband signal which is the output of the RF receiver **14***fq*, the third embodiment is not limited thereto. FIG. **13** is a block diagram illustrating the internal configuration of a radar device **1***g* according to Modification 1 of the third embodiment.

For example, a radar receiver **3***g* shown in FIG. **13** uses ND converters **18-1** to **18-4** for converting baseband signals obtained in RF receivers **14***f***1** to **14***f***4** into discretely sampled digital signals respectively. Moreover, in the radar receiver **3***g*, phase shifters **42-1** to **42-4** give phase rotations to the discretely sampled digital signals respectively. Moreover, the signal adder **33** adds the outputs of the phase shifters **42** in the same manner as in the radar device **1***f* according to the third embodiment.

By the configuration, the same effect as in the radar device **1***f* according to the third embodiment can be obtained in the radar device **1***g*. In Modification 1 of the third embodiment, a larger number of ND converters are required but digital phase control can be given to obtain higher accuracy than analog phase control.

Although various embodiments have been described with reference to the accompanying drawings, it is a matter of course that the radar device according to the invention is not limited to the examples. It is obvious that various changes or modifications can be thought of in the category described in the scope of claim by those skilled in the art, and it is to be understood that those are included in the technical scope of the invention.

Incidentally, in the invention, when the average reception signal power in the reception antenna ANTs varies widely in the case where the reception antenna ANTs is changed in accordance with the measurement environment around the radar device **1** or the like, the attenuator **4** may change its attenuation quantity in accordance with the average reception signal power.

Incidentally, this application is based on Japanese Patent Application (Patent Application 2010-161799) filed on Jul. 16, 2010 and the contents of which are incorporated herein by reference.

INDUSTRIAL APPLICABILITY

The radar device according to the invention is useful as an array radar device in which phase shift quantities in a plurality of antennas are corrected properly without influence on a measurement time or measurement distance range so that deterioration of accuracy of estimation of the arrival angle of a target is suppressed.

REFERENCE SIGNS LIST

1, **1***a*, **1***b*, **1***c*, **1***d*, **1***e*, **1***f*, **1***g* radar device
2 radar transmitter
3, **3***a*, **3***b*, **3***c*, **3***d*, **3***e*, **3***f*, **3***g* radar receiver
4 attenuator
5 transmission signal generator
6 LPF
7 RF transmitter
8, **16**, **28** frequency converter
9, **15**, **27** power amplifier
10 directional coupler
11, **11***a*, **11***b* switch
12, **12***c*, **12***e*, **12***f* switch controller
13, **13***a*, **13***a***1**, **13***a***2**, **13***a***3**, **13***a***4**, **13***b***1**, **13***b***2**, **13***b***3**, **13***b***4** signal combiner
14, **14***a*, **14***a***1**, **14***a***2**, **14***a***3**, **14***a***4**, **14***b***1**, **14***b***2**, **14***b***3**, **14***b***4**, **14***f***1**, **14***f***2**, **14***f***3**, **14***f***4** RF receiver
17, **17***a*, **17***d*, **17***e* signal processor
18, **18-1**, **18-2**, **18-3**, **18-4** ND convertor
19 reference transmission signal generator
20 correlation value calculator
21 timing controller
22 phase shift quantity calculator
23 phase corrector
24 storage
25 arrival angle and distance estimator
29, **31** second switch
30 intersystem fixed phase error storage
32-1, **32-2**, **32-3**, **32-4** phase shifter
33 signal adder
40 transmission signal changer
41 phase controller
42 phase shifter
ANT**0** transmission antenna
ANT**1** to ANT**4** reception antenna
Lo oscillator

The invention claimed is:

1. A radar device for transmitting a high-frequency transmission signal intermittently in a transmission cycle having a predetermined transmission period and a non-transmission period, receiving a signal reflected by a target by using a plurality of reception antennas, and detecting the target based on the reflected signal, the radar device comprising:

a transmission signal generator which generates a transmission signal in baseband;

a RF transmitter which converts the transmission signal generated by the transmission signal generator into a high-frequency transmission signal;

a directional coupler which distributes the high-frequency transmission signal converted by the RF transmitter in accordance with a predetermined signal power ratio;

a level adjuster which adjusts the high-frequency transmission signal distributed by the directional coupler to a predetermined level;

a signal combiner which combines a signal output from the level adjuster and a reception signal received by the reception antennas;

a RF receiver which converts the signal combined by the signal combiner into a reception signal in the baseband;

a reference transmission signal generator which generates a reference transmission signal the same as the transmission signal generated by the transmission signal generator;

a correlation value calculator which calculates a correlation value between the reference transmission signal

generated by the reference transmission signal generator and the reception signal converted by the RF receiver;

a phase shift quantity calculator which calculates a phase shift quantity in arbitrary one of the reception antennas based on the correlation value in a reference reception antenna which is specific one of the reception antennas and the correlation value in any one of the other reception antennas; and

a phase corrector which corrects a phase component of the correlation value in the arbitrary reception antenna based on the phase shift quantity calculated by the phase shift quantity calculator.

2. The radar device according to claim **1**, further comprising:

a first switch which changes the reception antennas sequentially and selects a single reception antenna from the reception antennas,

wherein the signal combiner combines the signal output from the level adjuster and a reception signal received by the single reception antenna selected by the first switch in the transmission period.

3. The radar device according to claim **2**, further comprising:

a switch controller which controls the first switch in sync with the transmission cycle of the transmission signal generated by the transmission signal generator.

4. The radar device according to claim **3**, wherein the level adjuster attenuates the high-frequency transmission signal output from the directional coupler to such a degree that the high-frequency transmission signal becomes sufficiently higher than the reception signal in the transmission period.

5. The radar device according to claim **3**, further comprising:

an A/D converter which converts the reception signal converted by the RF receiver into digital data.

6. The radar device according to claim **3**, further comprising:

a timing controller which notifies of a timing of completion of changing of the reception antennas by the switch controller through the first switch,

wherein the phase shift quantity calculator calculates a phase shift quantity in any one of the other reception antennas based on the correlation value in the reference reception antenna and the correlation value in any one of the other reception antennas calculated by the correction value calculator based on the notification of the timing by the timing controller.

7. The radar device according to claim **6**, further comprising:

a storage which stores the correlation value having the phase component corrected by the phase corrector with respect to each of the reception antennas; and

an arrival angle and distance estimator which calculates an arrival angle of the target and a distance to the target based on the correlation value stored in the storage.

8. The radar device according to claim **7**, further comprising:

a second switch which switches whether inputting of the high-frequency transmission signal attenuated by the level adjuster to the signal combiner is blocked or not,

wherein the reception signal received by each of the reception antennas includes a crosstalk signal that is the transmitted high-frequency transmission signal coming to each of the reception antennas;

wherein the correlation value calculator calculates the correlation value in each of the reception antennas in the timing of arrival of the crosstalk signal due to blocking inputting of the attenuated high-frequency transmission signal to the signal combiner by the second switch; and

wherein the phase shift quantity calculator calculates intersystem phase error from each of the reception antennas to the first switch based on the phase component of the correlation value calculated by the correlation value calculator in the timing of arrival of the crosstalk signal and the phase shift quantity in each of the reception antennas in the timing of completion of changing of the reception antennas.

9. The radar device according to claim **8**, further comprising:

a reference phase storage which stores the intersystem phase error calculated by the phase shift quantity calculator as a reference phase value with respect to each of the reception antennas,

wherein the correlation value calculator calculates the correlation value in each of the reception antennas in the timing of arrival of the crosstalk signal which comes to the reception antenna;

wherein the phase shift quantity calculator calculates the phase shift quantity in the reception antenna based on the phase component of the correlation value in the reception antenna in the timing of arrival of the crosstalk signal and the reference phase value stored in the reference phase storage; and

wherein the phase corrector corrects the phase component of the correlation value in the reception antenna calculated by the correlation value calculator based on the phase shift quantity calculated by the phase shift quantity calculator.

10. The radar device according to claim **6**, further comprising:

a second switch which switches whether inputting of the high-frequency transmission signal attenuated by the level adjuster to the signal combiner is blocked or not,

wherein the switch controller controls the second switch so that whether inputting of the high-frequency transmission signal to the signal combiner is blocked or not, is switched in accordance with a cycle of sequentially changing the reception antennas.

11. The radar device according to claim **6**, further comprising:

an intersystem fixed phase error storage which stores intersystem fixed phase error from each of the reception antennas to the first switch,

wherein the phase shift quantity calculator corrects the phase shift quantity in any one of the other reception antennas inclusive of the intersystem fixed phase error stored in the intersystem fixed phase error storage.

12. The radar device according to claim **2**, further comprising:

a switch controller which controls the transmission signal changer to change the signal combiner units sequentially in sync with the transmission cycle of the transmission signal generated by the transmission signal generator.

13. The radar device according to claim **1**, wherein the signal combiner includes a plurality of signal combiner units each of which combines the signal output from the level adjuster and a reception signal received by corresponding one of the reception antennas; and

the radar device further comprising:

a transmission signal changer which selects one of the signal combiner units and inputs the signal output from the level adjuster to the selected signal combining unit.

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